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Lime Spray Dryer Flue Gas Desulfurization Computer Model Users Manual

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Lime Spray Dryer Flue Gas Desulfurization Computer Model Users Manual

by

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16. ABSTRACT The report describes a lime spray dryer/baghouse (FORTRAN) computer model that simulates SO2 removal and permits study of related impacts on design and economics as functions of design parameters and operating conditions for coal-fired electric generating units. The model allows evaluation of several potential utility design and operating conditions for quick comparative costs of lime spray drying options on a common cost basis. Recycle of solids is inherent in the model as are the costs of both waste solids collection and disposal. An option permits the model to delete these costs so that lime spray dryer scrubbing costs may be compared with those from other FGD processes. Two significant limitations of the model are: the SO2 removal is based on operating parameter ranges and results developed for low-sulfur coal applications (data on high-sulfur coal applications are lacking) and only an overall system SO2 removal efficiency (without separate spray dryer and baghouse components) is calculated. The model projections using medium (2% sulfur) and high sulfur coal may be in error, with error increasing with increasing coal sulfur content. Means of overcoming these limitations are proposed. The users manual describes the model and instructions for its use, required input data are detailed, and sample computer runs with output are provided to guide users in identifying applications.

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a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Mathematical Models	Pollution Control	13B	12A
Flue Gases		Stationary Sources	21B	
Coal			21D	
Desulfurization			07A, 07D	
Calcium Oxides			07B	
Spray Drying			14H	

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ABSTRACT

The Tennessee Valley Authority (TVA), in cooperation with the U.S. Environmental Protection Agency (EPA), has developed a FORTRAN computer model capable of generating conceptual designs and process economics for a lime-based spray dryer/baghouse flue gas desulfurization (FGD) system. The spray dryer/baghouse FGD system is based on the use of a spray dryer with a single rotary atomizer and a side gas exit. The flue gas from the spray dryer flows through a reverse-air, utility-type baghouse and then an induced-draft fan to the stack. The model allows for variations in the spray dryer and baghouse design parameters and operating conditions, as well as variations in the coal composition and the required SO_2 removal to be simulated and the resulting impact on the system design and economics to be investigated.

The model is not intended to project the economics of an individual system to a high degree of accuracy. Instead, it is designed to allow prospective users to evaluate several potential design and operating conditions and quickly project comparative costs for the lime spray dryer FGD system case variations on a common cost basis. The process economics for a model cannot be directly compared with those for a wet limestone-scrubbing system since the process economics generated by the lime spray dryer computer model include the costs associated with both the collection and the disposal of fly ash (these costs are inherent to the process). The Shawnee lime/limestone computer model projections and most other wet-scrubbing cost estimates do not include these costs. However, an option has been included in the lime spray dryer computer model which allows the user to delete these costs, and hence generate a scrubbing-only cost for comparison with other FGD process cost estimates.

There are currently two significant limitations to the capabilities of this lime spray dryer FGD computer model. The equations for SO_2 removal are based on operating parameter ranges and results developed for low-sulfur coal applications, and because of the lack of sufficient data on high-sulfur coal applications, do not contain correction factors for operation with high-sulfur coals where higher inlet SO_2 concentrations are encountered. Thus, the design and economics projected by the model for medium- (approximately 2% sulfur) or higher sulfur coal applications may be in error with the error increasing as the percent sulfur level increases. This limitation may be overcome by inputting specific operating parameters, and thereby running the model in a "force-through" mode. The second limitation is that the equations calculate only an overall SO_2 removal efficiency without providing a breakdown of this overall SO_2 removal into separate spray dryer and baghouse components. Both of these limitations should be removed as data from the ongoing high-sulfur test program at TVA become available.

The users manual provides a general description of the lime spray dryer FGD computer model and detailed instructions for its use. It describes and explains the user-supplied input data which are required such as boiler size, coal characteristics, and SO_2 removal requirements. The users manual provides additional information concerning the use of the overall model as well as sample runs to serve as a guide to prospective users in identifying applications. Examples of the output from the model, including material balance, equipment list, and detailed capital investment and annual revenue requirements tables, are also shown. The FORTRAN-based model is maintained by TVA, from whom tape copies of the model or individual computer runs may be obtained.

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ABBREVIATIONS AND CONVERSION FACTORS

ABBREVIATIONS

aft3/min	actual cubic feet per minute
Btu	British thermal unit
°F	degrees Fahrenheit
dia	diameter
FGD	flue gas desulfurization
ft	feet
ft^2	square feet
ft3	cubic feet
gal	gallon
Ggal	10^9 gallons
gpm	gallons per minute
gr	grain
hp	horsepower
hr	hour
in.	inch
k	thousand or kilo
kW	kilowatt
kWh	kilowatthour
lb	pound
M	million or mega
mi	mile
mo	month
MW	megawatt
ppm	parts per million
psig	pounds per square inch (gauge)
rpm	revolutions per minute
sec	second
sft3/min	standard cubic feet per minute (60°F)
SS	stainless steel
yr	year

CONVERSION FACTORS

EPA policy is to express all measurements in EPA documents in metric units. Values in this report are given in British units for the convenience of engineers and other scientists accustomed to using the British systems. The following conversion factors may be used to provide metric equivalents.

To convert British		Multiply by	To obtain Metric (SI)	
ac	acre	0.405	hectare	ha
Btu	British thermal unit	0.252	kilocalories	kcal
^oF	degrees Fahrenheit minus 32	0.5556	degrees Celsius	^oC
ft	feet	0.3048	meters	m
ft^2	square feet	0.0929	square meters	m^2
ft^3	cubic feet	0.02832	cubic meters	m^3
ft/min	feet per minute	0.00508	meters per second	m/s
ft^3/min	cubic feet per minute	0.000472	cubic meters per second	m^3/s
gal	gallons (U.S.)	3.785	liters	L
gpm	gallons per minute	0.06308	liters per second	L/s
gr	grains	0.0648	grams	g
gr/ft^3	grains per cubic foot	2.288	grams per cubic meter	g/m^3
hp	horsepower	0.746	kilowatts	kW
in.	inches	0.0254	meters	m
lb	pounds	0.4536	kilograms	kg
lb/ft^3	pounds per cubic foot	16.02	kilograms per cubic meter	kg/m^3
lb/hr	pounds per hour	0.126	grams per second	g/s
mi	miles	1609	meters	m
psi	pounds per square inch	6895	pascals (newton per square meter)	Pa (N/m^2)
rpm	revolutions per minute	0.1047	radians per second	rad/s
sft^3/min	standard cubic feet per minute (60^oF)	1.6077	normal cubic meters per hour (0^oC)	m^3/hr (0^oC)
ton	tons (short)	0.9072	metric tons	tonne
ton/hr	tons per hour	0.252	kilograms per second	kg/s

Note: Metric units are those of the Systems International (SI) metric system.

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LIME SPRAY DRYER FLUE GAS DESULFURIZATION COMPUTER MODEL

USERS MANUAL

EXECUTIVE SUMMARY

The lime spray dryer flue gas desulfurization (FGD) computer model was developed by the Tennessee Valley Authority (TVA) to model a lime spray dryer/baghouse FGD system. The model is capable of projecting a material balance, an equipment list, and the capital investment and revenue requirements for a spray dryer/baghouse FGD system based on the user-specified input data. The purpose of this computer model is to permit the rapid estimation of the relative economic impacts of variations in: process design parameters (e.g., absorber residence time and baghouse air-to-cloth ratio), coal compositions, SO_2 removal efficiencies, and spray dryer operating conditions (e.g., approach-to-saturation temperature and lime stoichiometry). The model is not intended to compute the economics of an individual system to a high degree of accuracy. Instead, it is designed to allow prospective users to evaluate several potential design and operating conditions and quickly project comparative costs for these case variations on a common basis.

MODEL BASIS

The lime spray dryer FGD computer model is based on the previous generic conceptual designs of the lime spray dryer/baghouse FGD technology prepared by TVA and the existing information available on commercially operating spray dryer/baghouse FGD systems. Although the numerous spray dryer FGD vendors have slightly different process designs, most of the differences are focused in the spray dryer vessel itself. The spray dryer vessel in this model is based on the Niro Atomizer, Inc., design with a single rotary atomizer, a side gas exit, and a single recirculating slurry feed loop with a head tank to feed the atomizer. Other designs have been used by vendors, but most of the utility installations currently being designed, built, or operated are using the Niro technology. For this reason, the Niro spray dryer design was selected as the basis for this computer model. The remaining components of the system reflect a generic process design including a utility-type, reverse-air baghouse; a lime preparation system (currently limited to a ball-mill-type slaker); an FGD waste recycle system; and an onsite landfill for waste disposal. The current model cannot simulate either once-through operation (i.e., no recycle) or pond disposal of the waste.

Process Description

The spray dryer/baghouse FGD system is a relatively simple process with few major equipment items as shown in the process flow diagram in Appendix A. The flue gas from the boiler air heater enters the spray dryer vessel at about 300°F through an inlet scroll around the atomizer and is intimately mixed with the atomized absorbent slurry. The particulate-laden flue gas swirls downward through the spray dryer, makes a 180-degree turn, and exits through a side gas exit duct inserted into the centerline of the spray dryer. As the flue gas passes through the spray dryer, the SO_2 in the flue gas is absorbed into the alkaline feed slurry and reacts with the available lime to form a mixture of calcium-sulfur salts. Simultaneously, the water in the atomized slurry is evaporated by the energy absorbed from the flue gas, thus cooling and humidifying the flue gas. The spray dryer is sized such that the water in the feed slurry is evaporated before the flue gas leaves the spray dryer. The combination of the swirl imparted to the flue gas and the conical bottom of the spray dryer results in some of the FGD solids falling to the conical bottom of the spray dryer. The particulate-laden flue gas from the spray dryer passes to the baghouse. The SO_2 in the flue gas continues to react with the absorbent particles until it passes through the filter cake in the baghouse. The clean flue gas from the baghouse passes through the induced-draft fan to the stack. The entrained particulate matter (both fly ash and FGD solids) which is collected on the fabric filters as a cake is periodically dislodged by reverse airflow and falls into hoppers from which it is removed and conveyed to either a particulate surge bin (if baghouse recycle is necessary for the process) or a particulate disposal silo. The waste from the particulate disposal silo is trucked to the landfill site.

The solids from the spray dryer cone are discharged through a double-flap tipping valve to a mechanical conveyor, are moved to a bucket elevator, and are then transported to the spray dryer particulate recycle silo. The recycle solids from the silo are reslurried with water and pumped to the combined feed tank where they are mixed with fresh lime slurry in a predetermined ratio. The resulting combined feed slurry is fed to the spray dryer using a flooded-loop design. This flooded-loop design allows a constant flow of feed slurry to be pumped to the head tank located above the spray dryer. The slurry required in the process is bled off from the head tank to the atomizer while the remaining slurry returns to the combined feed tank to be recirculated. The slurry flow to the atomizer is controlled by a pinch valve between the head tank and the atomizer.

High-calcium pebble lime is received by either rail or truck and conveyed to a lime storage silo. As required in the process, the lime is transported to a day bin and then to the ball mill slakers. The resulting lime slurry overflows to a slaker product tank and then is pumped to the combined feed tank where it is mixed with the recycle slurry for use in the process.

MODEL CAPABILITY

The lime spray dryer FGD computer model generates a complete conceptual design package for a lime spray dryer/baghouse FGD system including the landfill for disposal of the wastes. The model is divided into four major sections: (1) material balance, (2) equipment sizing, (3) capital investment, and (4) annual revenue requirements. The material balance section projects the flue gas composition and flow rate from the boiler and all process stream compositions and flow rates based on the input data. The key design equations which relate the overall SO_2 removal efficiency to the major process design variables (lime stoichiometry and approach-to-saturation temperature) are based on published data. TVA was responsible for selecting the best available equations and constructing the material balance section of the model. The equipment sizing section is based on TVA's previous experience with the Shawnee lime/limestone computer model. The equipment sizing is determined by the stream flow rates from the material balance, any size limitations of the particular equipment item, and the number of parallel operating equipment trains. These equipment sizes are then used in the capital investment section to estimate the costs for both the equipment and the field materials and labor required for the installation of the equipment. The summation of the equipment and installation costs results in an overall direct investment cost for each of the seven processing areas in the spray dryer/baghouse system. The direct investment for these areas is summed to obtain a total process capital cost. After adding services and miscellaneous costs and the costs for the landfill to obtain the total direct investment, the various indirect investments and other capital costs are calculated. The sum of all of these costs is the total capital investment. In the annual revenue requirements section, first-year and levelized annual revenue requirements and lifetime revenue requirements are estimated based on the results from the material balance (raw material requirements, etc.), the equipment sizing (electrical energy costs), and the capital investment sections (levelized capital charges).

The model output includes a detailed material balance, equipment list, landfill design, and capital investment and annual revenue requirement summary tables. It also includes a listing of the major process design conditions including lime stoichiometry, SO_2 removal efficiency, etc.

Although the model is designed for flexibility, the model is most accurate for the variable ranges which were anticipated during its development. These anticipated ranges for basic design parameters are shown below:

Variable	Range
Power plant	New, 50-1,300 MW
Fuel sulfur content	0.5-5%[a]
Fuel SO_2 content	1.0-9.0 lb SO_2/MBtu
SO_2 concentration	400-4,000 ppm
Approach-to-saturation temperature	15-50°F
Spray dryer residence time	5-12 sec
Number of operating spray dryers	1-10
Number of spare spray dryers	0-10
Number of spare lime preparation units	0-10

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Variable	Range
SO_2 removal efficiency	49-97%
Fly ash removal efficiency	1-99.9%
Baghouse pressure drop	4-8 in. water
Air-to-cloth ratio	1.5-3.0 aft^3/min/ft^2 cloth area

a. For coal sulfur levels above 2%, the model tends to underestimate the required lime stoichiometry, and hence the user should operate the model in the "force-through" mode (i.e., specifying both the lime stoichiometry and the overall SO_2 removal efficiency--see later discussion under model options).

Note: The variable ranges were established for model development purposes. Values beyond these ranges are not necessarily invalid, but the potential for error is greater when these ranges are exceeded.

MODEL USAGE

While the lime spray dryer FGD computer model is designed to be used by utility companies or architectural and engineering firms involved in the selection of SO_2 removal facilities, it has the potential for use by others interested in SO_2 removal technologies. Although it is not intended to be used for projecting a final design, the model can be used to assist in the evaluation of system alternatives prior to a detailed design. The model should also be useful for evaluating the impact of changing various design or operation variables on the process economics. While the model is not meant to be used for comparing the process economics of a lime spray dryer/baghouse FGD system with those of alternative FGD processes, these comparisons can be made if the user is careful to maintain comparability between the design conditions used in the lime spray dryer FGD computer model and those for the alternative FGD processes.

The body of this report contains a discussion of the information necessary and the input data required to run the overall computer model. This discussion includes a more detailed description of the lime spray dryer/baghouse system, the input data set, and the options available to the user. Also discussed is the procedure for either acquiring a tape copy of the model or having example runs prepared.

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LIME SPRAY DRYER FLUE GAS DESULFURIZATION COMPUTER MODEL

USERS MANUAL

INTRODUCTION

The lime spray dryer flue gas desulfurization (FGD) computer model projects the major design and operating conditions and the economics for a lime spray dryer/baghouse FGD system for coal-fired utility applications based on the user-supplied input data. The model was developed by the Tennessee Valley Authority (TVA) in cooperation with the U.S. Environmental Protection Agency (EPA). The model is general in nature and is capable of generating conceptual designs and process economics for a lime spray dryer/baghouse FGD system for a range of power plant, coal, and SO_2 removal efficiency conditions.

The economic results are similar to those of preliminary conceptual design evaluations in which the absolute accuracy typically ranges from -15% to +30% (the difference between the model projection and the cost of an identically designed real system). The comparative accuracy between different model projections is much better, ranging from only -10% to +10%. The model is most useful for preparing preliminary cost comparisons of spray dryer FGD alternatives. These alternatives can be process design parameters (such as the flue gas residence time in the spray dryer or the baghouse air-to-cloth ratio), coal compositions, SO_2 removal efficiencies, or spray dryer operating conditions (such as lime stoichiometry and approach-to-saturation temperature). Although the model is not intended to compute the economics of a specific system to a high degree of accuracy, it allows the user to rapidly estimate preliminary cost data for process variations on a common basis. Thus, utility companies and architectural and engineering contractors, who are involved in the selection and design of FGD facilities, will find the model useful. The model is primarily intended for estimating the costs for a new unit although the user can, by estimating a retrofit factor, simulate a retrofit application.

The model is maintained by TVA, from whom tape copies of the model are available. This manual provides a general description of the model and its uses. It also provides a more detailed description of the lime spray dryer/baghouse system, the input data set, and the options available to the user.

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GENERAL INFORMATION

BACKGROUND

The spray dryer FGD technology evolved in the United States in part from the FGD studies begun in the 1960s in which limestone was injected into the flue gas ductwork as a dry powder and collected downstream from the injection point in either baghouses or electrostatic precipitators (ESPs). Although these dry absorption studies were initially disappointing, the potential benefits of such uncomplicated approaches to FGD have maintained utility interest in this technology. This so-called dry-scrubbing technology received renewed interest in the mid-1970s after initial pilot-plant work with nahcolite, a naturally occurring sodium bicarbonate waste material from oil shale mining, showed promise as a dry absorbent capable of achieving 70-80% SO_2 removal at moderate stoichiometries for low-sulfur (western) coals. However, the uncertainty surrounding the availability of nahcolite in commercial quantities led to the study of other technologies including the use of a spray dryer. The spray dryer, although requiring that the lime or soda ash be injected in the form of an alkaline feed slurry to make them sufficiently reactive to achieve the necessary SO_2 removal efficiencies at moderate stoichiometries, generated a dry waste product and appeared to be a much simpler process than conventional wet FGD scrubbing systems.

Because of these potential advantages, the use of this spray dryer FGD technology has expanded quite rapidly in the past few years such that numerous companies and consortia are now offering this technology commercially. Eighteen full-scale, utility spray dryer FGD units representing nearly 7,000 MW of new, coal-fired utility capacity are currently under contract or in various stages of design, construction, or operation. Most of these applications have been in the upper Midwest where low-sulfur bituminous or subbituminous coal or lignite is being burned and only 70-80% SO_2 removal efficiency is required (1). This growth is a result of both the potential technical and economic advantages of the technology and the increased use of western low-sulfur coals by utilities for which spray drying is particularly suited. Also important is the broad base of previous design and operating experience with spray dryers, particulate collection devices, and lime preparation equipment in other industries.

Because of TVA's continuing interest in the development of new FGD technologies, TVA has been following the progress of this spray dryer FGD technology since its inception in the mid-1970s. Recently TVA, in cooperation with two major equipment suppliers, has become more actively involved in the development of this lime spray dryer FGD technology with the installation of two small pilot plants at its FGD test facility at the Shawnee Steam Plant

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near Paducah, Kentucky. These TVA-sponsored tests, which began in early 1983, are focused on developing this technology for potential use in high-sulfur coal applications (2).

EPA sponsored and funded much of TVA's early monitoring efforts and the previous conceptual design and cost estimates of this technology. Because of the potential advantages and the commercial utility interest in this technology, EPA decided in 1982 to fund the development by TVA of a computer model to generate conceptual designs and process economics for lime spray dryer/baghouse systems. The development of this model was patterned after the Shawnee lime/limestone computer model which was previously developed by TVA for EPA (3).

MODEL BASIS

The basis for the lime spray dryer FGD computer model is a generic spray dryer/baghouse system using lime as the alkali absorbent. Although numerous spray dryer FGD vendors have slightly different process designs, most of the differences are concentrated in the spray dryer vessel itself. The spray dryer vessel in this model is based on the Niro Atomizer, Inc., design with a single rotary atomizer, a side gas exit, and a single recirculating slurry feed loop with a head tank to feed the atomizer. Other designs have been used by some vendors, but most of the utility installations currently being designed, built, or operated are using the Niro technology. For this reason, the Niro spray dryer design was selected as the basis for this computer model. The remaining components of the system reflect a generic process design including a utility-type, reverse-air baghouse; a lime preparation system (currently limited to a ball-mill-type slaker); an FGD solids recycle system; and an onsite landfill for waste disposal. The current model cannot simulate either once-through operation (i.e., no recycle) or pond disposal of the waste. This generic spray dryer/baghouse system is described in more detail in the following sections.

Process Description

The spray dryer/baghouse FGD system is a relatively simple process with few major equipment items as shown in the process flow diagram in Appendix A. The flue gas from the boiler air heater enters the spray dryer vessel at about 300°F through an inlet scroll around the atomizer and is intimately mixed with the atomized absorbent slurry. The particulate-laden flue gas swirls downward through the spray dryer, makes a 180-degree turn, and exits through a side gas exit duct inserted into the centerline of the spray dryer. As the flue gas passes through the spray dryer, the SO_2 in the flue gas is absorbed into the alkaline feed slurry and reacts with the available lime to form a mixture of calcium-sulfur salts. Simultaneously, the water in the atomized slurry is evaporated by the heat from the flue gas, thus cooling and humidifying the flue gas. The spray dryer is sized such that the water in the feed slurry is evaporated before the flue gas leaves the spray dryer. The combination of the swirl imparted to the flue gas and the conical bottom of the spray dryer results in some of the FGD solids falling to the conical bottom of the spray dryer. The particulate-laden flue gas from the spray dryer passes to the baghouse. The SO_2 in the flue gas continues to react with the absorbent particles until it passes through the filter cake in the baghouse. The clean flue gas from the baghouse passes through the induced-draft (ID) fan to the stack. The entrained particulate matter (both fly ash and FGD solids) which is collected on the fabric filters as a cake is periodically dislodged by reverse airflow and falls into hoppers from which it is removed and conveyed to either a particulate surge bin (if baghouse recycle is necessary for the process) or a particulate disposal silo. The waste from the particulate disposal silo is trucked to the landfill site.

The solids from the spray dryer cone fall to a mechanical conveyor, are moved to a bucket elevator, and are transported to the spray dryer particulate recycle silo. The recycle solids from the silo are reslurried with water and pumped to the combined feed tank where they are mixed with fresh lime slurry in a predetermined ratio. The resulting combined feed slurry is fed to the spray dryer using a flooded-loop design. This flooded-loop design allows a constant flow of feed slurry to be pumped to the head tank located above the spray dryer. The slurry required in the process is bled off from the head tank to the atomizer while the remaining slurry returns to the combined feed tank to be recirculated. The slurry flow to the atomizer is controlled by a pinch valve between the head tank and the atomizer.

High-calcium pebble lime is received by either rail or truck and conveyed to a lime storage silo. As required in the process, the lime is transported to a day bin and then to the ball mill slakers. The resulting lime slurry overflows to a slaker product tank and then is pumped to the combined feed tank where it is mixed with the recycle slurry for use in the process.

Processing Areas

The lime spray dryer FGD computer model divides the spray dryer/baghouse FGD system into seven major processing areas: raw material handling, feed preparation, gas handling, SO_2 absorption, particulate removal, spray dryer solids handling, and baghouse solids recycle (if necessary). The landfill is included in the model as a separate area. Each of these seven major processing areas is discussed in more detail below, along with a description of the equipment and facilities included within the battery limits of each processing area. The basis for the design of the equipment in these areas is discussed in the following section.

Raw Material Handling--

This area contains the equipment for receiving pebble lime by truck or rail, storing the lime until needed in the process, and maintaining a supply of lime to the feed bin weigh feeders in the feed preparation area. Major equipment in this area includes lime storage silo(s) capable of storing a 30-day supply of lime. Other equipment consists of numerous conveyors and elevators to transport lime, as well as feed bin(s) to store and supply lime to each train of preparation equipment in the feed preparation area. The feed bin(s) are designed to provide 12 hours of storage capacity.

The direct investment costs for the raw material-handling area include the costs for all of the lime receiving equipment and the field construction materials and labor to install the equipment up to, and including, the lime feed bin.

Feed Preparation--

This area includes the equipment necessary for preparing both the fresh lime slurry and the waste recycle slurry which are then mixed to generate the alkaline feed slurry for the SO_2 absorption area. The lime slurry preparation equipment includes slakers for generating a lime slurry at a concentration of 20% to 25% solids (as specified in the input data set) as well as a feeder and conveyor to feed raw lime to the slaker. It also includes a slaker product tank and associated agitators and pumps. The number of operating slakers and associated equipment is determined by the model. The number of spare slakers is specified by the user.

The solids recycle slurry preparation equipment includes a weigh feeder and tank, agitator, and pumps. Only one train of recycle slurry preparation equipment is provided.

The fresh lime and FGD solids recycle slurries are pumped to and mixed in a single combined feed tank. The combined feed tank is designed to provide a surge capacity of 8 hours. Also included is an agitator and pumps.

The direct investment costs for the feed preparation area include the costs for all of the preparation equipment (both lime and recycle slurry) and the field construction materials and labor to install the equipment from the lime and recycle bin weigh feeders up to, and including, the pumps to feed the combined feed slurry to the spray dryer.

Gas Handling--

This area contains all of the flue gas ductwork included in the FGD system. It also includes an ID fan (relative to the FGD system) located downstream of the baghouse and sized to overcome the pressure drop through the FGD system. Flue gas from the power plant is fed to a common plenum from which each of the spray dryers is supplied with flue gas. The flue gas ductwork includes this inlet plenum, the ductwork to and from the spray dryers, a common plenum connecting the feed to the baghouse(s), the ductwork from the baghouse to the ID fan, the ductwork from the ID fan to the stack plenum, the emergency bypass ductwork around the spray dryers, and the hot gas or warm gas bypass ductwork (if required).

The direct investment costs for the gas-handling area include costs for the flue gas equipment and the field materials and labor to install the equipment and ductwork from the inlet FGD plenum up to, but excluding, the stack plenum. Costs for the FGD fans, the hot or warm gas bypass ductwork (if necessary), and emergency bypass ductwork are included; however, costs for the power plant ID fan (to provide balance-draft operation of the boiler), the stack plenum, and the stack are considered to be an integral part of the power plant and are, therefore, not included in the cost estimate for the FGD system.

SO_2 Absorption--

This area includes only the spray dryers and associated equipment, i.e., the rotary atomizer and the head tank. The slurry piping to feed the combined slurry to the head tank via a recirculating flooded loop is included. (The recirculating pumps are included in the feed preparation area.) The recirculating flooded-loop design involves pumping the feed slurry to the head tank in much greater quantities than needed by the process. The combined feed slurry needed in the process is bled off from the head tank while most of the slurry returns to the combined feed tank.

The direct investment costs for the SO_2 absorption area include the cost for the spray dryers (including the internals such as the atomizer, valves, inlet scroll, etc.), the head tanks, and all of the feed slurry piping, as well as the field construction materials and labor to install the equipment in the spray dryer area.

Particulate Removal--

The particulate removal area includes the baghouse(s) and the particulate removal and storage facilities associated with removing the particulates from the flue gas and transporting the waste to the disposal silo. In addition to the baghouse, other major equipment includes numerous conveyors, an elevator, two baghouse particulate surge bins (totaling 1 hour of storage capacity), and a particulate disposal silo (24 hours of storage capacity).

The direct investment costs for the particulate removal area include the costs for the equipment and the field construction materials and labor to install the baghouse, the baghouse particulate conveyors, the particulate surge bins, the particulate disposal silo, and the associated silo equipment.

Spray Dryer Solids Handling--

This area provides conveyors to transport the FGD solids collected in the spray dryer to either the spray dryer particulate recycle silos (24 hours of storage capacity) for the material to be reused or to the spray dryer particulate surge bin for the material to be sent to waste. The bin and silo are also included in this area.

The direct investment costs for the spray dryer solids-handling area include the costs for all of the equipment and the field construction materials and labor to install the equipment.

Baghouse Solids Recycle--

This area includes a conveyor and a baghouse recycle silo (12 hours of storage capacity) and associated silo equipment to provide additional recycle FGD solids to the feed preparation area if needed by the process. The model is designed to use maximum recycle. Thus, if insufficient solids are collected in the spray dryer (which will typically occur in low-sulfur coal applications), the model includes this area to provide additional recycle from the baghouse.

The direct investment costs for the baghouse solids recycle area (if required by the process) include the costs for the baghouse recycle equipment and the field construction materials and labor to install this equipment.

Process Equipment Design Basis

Based on results from the material balance model section (i.e., stream flow rates and compositions) and some user-supplied variables (i.e., number of operating trains of equipment), the major process equipment is specified and then listed by major processing area. The equations for predicting the equipment costs were developed in 1983 based on vendor quotes and in-house cost estimating procedures. The design assumptions used as a basis for sizing or specifying the major process equipment included in the lime spray dryer/ baghouse FGD system are given below:

Lime Storage Silo--

A 30-day storage capacity is assumed for calculating the volume of the lime storage silos. The silos are concrete, with the height of the actual storage section of the silo assumed to be one and one-half times the diameter. Total height of the silo is equal to the height of the actual storage section plus the height of the conical carbon steel hopper plus 5 feet. When the lime storage requirements exceed the maximum silo size of 50 feet in diameter and 75 feet high (straight side), parallel storage silos of equal capacity are used. The conical hopper is constructed of carbon steel with a 60-degree slope to prevent unloading problems.

Lime Slaker--

Lime is slaked at slurry concentrations of 20% to 25% solids in a ball-mill-type slaker. The model calculates the size of parallel slaking trains based on the process requirements with two parallel slaking trains typical for larger lime requirements. The user specifies the number of spare slakers. The maximum slaker capacity is 33 tons of lime/hr. The spray dryer/baghouse FGD system is normally designed with either one 100% capacity slaker operating and one 100% capacity spare (for low lime consumption rates) or two 50% capacity slakers operating and one 50% capacity spare (for high lime consumption rates).

Fans--

The fans are centrifugal (double width, double inlet) ID fans with radial impellers and are constructed of carbon steel. They are equipped with variable-speed fluid drives. Fan horsepower is calculated based on the inlet gas flow rate and the calculated pressure drop for the spray dryer, baghouse, and duct. The total number of operating ID fans is determined based on the assumption that two ID fans are required per baghouse. The flow rate through each fan is then calculated and compared with a maximum size of 500,000 aft^3/min. If this maximum value is exceeded, additional fans are provided until the flow rate through each fan falls below the maximum value. No spare fans are included.

Spray Dryers--

The number of parallel spray dryers is either given as an input to the model or established by an override to the input value based on the minimum number of spray dryers required. The minimum number of spray dryers is calculated based on the volumetric flow rate of flue gas scrubbed, the residence time specified for the spray dryer (both determined based on the spray dryer outlet flue gas conditions), and the maximum spray dryer size of 50 feet in diameter by 35-1/2 feet high (straight side). The conical hopper is constructed of carbon steel with a 60-degree slope to minimize unloading problems. The volume of the cone, less an allowance for the internals, is included in the calculation of the spray dryer residence time since the cone operates empty. The user typically specifies the number of operating spray dryers; however, the model will compare the resulting size with the maximum available size and change the number of operating spray dryers, if necessary. The number of spare spray dryers is specified by the user (in the typical commercial utility application, a spare spray dryer train is included).

The spray dryers are sized based on a fixed straight-side height-to-diameter ratio of 0.71. Each spray dryer is insulated with 4 inches of rock wool and the entire spray dryer area is enclosed in a shell-type building (i.e., corrugated aluminum siding and roof supported by a structural steel skeleton) to minimize heat losses in the system.

Tanks, Agitators, and Slurry Pumps--

The sizing of the tanks, the agitators, and the slurry pumps for each of the areas is determined by utilizing the following procedures. The tank volume is calculated based on a TVA-assumed residence time. An additional 10% volume is added for freeboard. The tank height is assumed to be equal to tank diameter. All tanks are constructed of carbon steel, and all slurry tanks are neoprene- or flaked-glass lined. Each large tank is designed with four baffles and stiffening rings.

All slurry tanks are equipped with a pitched-blade, turbine agitator equipped with four blades. Agitator horsepower requirements are calculated on the basis of total torque, which is a function of the degree of agitation required (expressed as torque/unit volume), total tank volume, tank diameter, and the slurry specific gravity. Unit torque (torque/unit volume) for each tank is determined as a function of the percent solids in the slurry.

All slurry pumps are of a rubber-lined, centrifugal type with water seals and are equipped with either a variable- or constant-speed drive. Pumps are spared; the number of operating pumps is determined by process requirements.

Baghouse--

The baghouse is designed based on the user-specified number of baghouses, air-to-cloth ratio, and the flue gas flow rate. The air-to-cloth ratio is calculated based on the baghouse inlet flue gas conditions. The baghouse is a utility-type, reverse-air unit with Teflon-coated fiberglass bags 30 feet in length and 11-1/2 inches in diameter. If the number of baghouses is not specified in the data set, a default value of one baghouse is assumed.

Particulate Disposal Silos--

The particulate waste disposal silos are constructed of concrete with conical hoppers constructed of carbon steel (slope of 45 degrees). The silos are designed for a storage capacity of 24 hours with the height of the storage section equal to one and one-half times the diameter. The total height of the silo is equal to the height of the storage section plus the height of the conical hopper plus 10 feet. The maximum silo size is 50 feet in diameter and 75 feet high (straight side).

Elevators--

The elevators for the lime raw material and particulate disposal areas are of a continuous bucket type and are sized based on the projected flow rates calculated in the material balance. Elevator height depends on the total height of the silo plus 5 feet.

Conveyors--

The conveyors are either belt, screw, mechanical drag link, or pressure pneumatic type depending on the solids to be handled. The raw material-handling area conveyors are belt type and are sized based on the flow rates and conveying distances required. The screw conveyor is used in the feed preparation area to transport lime from the feed bin to the slaker and is sized to obtain the calculated lime flow rate. The mechanical drag link conveyor is used to transport the solids collected in the spray dryer. Pneumatic pressure and belt conveyors are used in the spray dryer and baghouse solids recycle and disposal areas and are sized to obtain the required flow rates and conveying distances. The pneumatic systems are used where dry solids are to be transported over long distances.

Piping--

Carbon steel pipe and gate valves are used for all waterlines. For slurry lines, rubber-lined carbon steel piping is used. Rubber-lined strainers are used for all pipes. For slurry lines less than 3-inch diameter, stainless steel plug valves are used. Eccentric plug valves are used for slurry lines between 3- and 10-inch diameters. Handwheel operators are used for all valves. Typical piping layouts are assumed based on the flow capacities and the number of trains. The piping costs are correlated with the flow rates (in gal/min) and the piping lengths (as taken from the assumed layout). Control valve costs are included in instrumentation.

Ductwork--

The ductwork is constructed of 3/16-inch Cor-Ten. All ductwork is insulated with 4-inch rock wool. The size of each duct is based on a square cross section and a nominal design gas velocity of 3,000 ft/min at local inlet conditions. Each spray dryer train includes two guillotine dampers and expansion joints. Two emergency bypass ducts, each designed for a minimum of 25% of the total gas flow rate from the boiler, are included in the costs. Each emergency bypass duct includes two louver-type and two guillotine dampers and expansion joints. The costs for the dampers, expansion joints, and insulation are included in the ductwork charges.

Foundations--

Concrete foundations for each equipment item are fixed according to equipment sizes. Foundations for a structure are estimated on the basis of the weight of the structure.

Structures--

Structural estimates are related to the spray dryer volume, baghouse volume, and the number of parallel trains. Structural steel costs for the SO_2 absorption area are included in the spray dryer equipment estimates and the building estimate. Costs for stairways, handrails, grids, etc., are included in the total estimate.

Electrical--

The electrical estimate is divided into four sections: (1) costs of feeder cables from the power plant transformer yard to field modules for each area; (2) transformer costs for each area; (3) costs of power supply from area field modules to individual motors; and (4) motor control costs between remote control center, field module location, and individual motors for each area. For each area, total connected motor horsepower is calculated for use in establishing costs for (1) and (2). Costs for (3) and (4) are based on individual motor sizes and number of connected motors. A typical layout is assumed for each area in reference to the power plant transformer yard, remote control center, and other areas.

Instrumentation--

Instrumentation costs are based on (1) fixed costs for instruments which do not change in size and cost with equipment and pipe size variations and (2) variable costs for instruments which increase in size and cost as equipment and pipe sizes increase. Each of these costs may be dependent upon the number of spray dryers, the number of slakers, the number of pumps, etc. Costs are included for control valves, graphic boards, panelboards, annunciator, air dryers, piping, and instrument cable and wiring systems.

Buildings--

The control room and motor control center are integrated with the power plant and prorated costs are included. Costs are included for a building to house the lime slaking facilities. Buildings to house the spray drying (SO_2 absorption area) equipment are included as appropriate. All buildings are sized as a function of the equipment size and number of equipment items and are constructed with concrete floors and corrugated aluminum siding supported by a steel frame. They are insulated to a value of R-19 using fiberglass insulation.

Landfill Construction--

Disposal landfill size is calculated based on the waste disposal flow rate from the material balance and the remaining life of the unit. It is designed with a square configuration and a cap sloping up to a point. The landfill design is shown in Appendix B, page B-37.

Process Chemistry

Although the overall chemistry of the SO_2 removal in the spray dryer/baghouse FGD system is known and the reaction mechanisms and rate controlling steps are thought to be understood, additional work is continuing toward a better understanding of the process chemistry such that further improvements in spray dryer performance can be achieved. The basic chemistry of the SO_2 reactions in the spray dryer/baghouse FGD system has been described in detail elsewhere (4,5,6).

In the lime spray dryer FGD process, an alkaline solution or slurry is atomized in the spray dryer to form a fine mist (approximately 50-100 micron droplets). The intimate mixing of the hot flue gas and this fine mist of alkaline slurry causes two simultaneous processes to occur: (1) the alkalinity in the droplets reacts with the SO_2, HCl, and CO_2 in the flue gas and (2) the water in the droplets evaporates to yield dry calcium-based particulate matter. The resulting reaction products are collected, along with fly ash from the boiler, in either the spray dryer or the baghouse as dry solids. The reaction mechanisms and rate controlling steps are somewhat different in the spray dryer and the baghouse, and therefore each of these will be discussed individually.

Spray Dryer--

The rate controlling step in the reaction between the SO_2 in the flue gas and the lime particles in the spray dryer is thought to be a gas-liquid phase reaction in which the SO_2 is absorbed into the slurry droplets. Once absorbed in the droplets, the following reactions occur:

$$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 \cdot 1/2H_2O \qquad (1)$$

$$Ca(OH)_2 + SO_3 + H_2O \rightarrow CaSO_4 \cdot 2H_2O \qquad (2)$$

$$Ca(OH)_2 + 2HCl + 4H_2O \rightarrow CaCl_2 \cdot 6H_2O \qquad (3)$$

In addition to these primary reactions, the following secondary reactions also occur:

$$CaSO_3 + 1/2O_2 \rightarrow CaSO_4 \qquad (4)$$

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \qquad (5)$$

However, as the hot flue gas and alkaline droplets mix and pass downward through the spray dryer, the water in the droplets evaporates and the droplets shrink resulting in less surface area for absorption. Eventually, most of the water evaporates and "dry" particulate matter composed of the reaction products, unreacted lime, and fly ash remains entrained in the flue gas. As the water in the atomized droplets evaporates, the lime in each droplet coalesces into a single particle. The low solubility of lime results in the formation of a highly porous outer layer surrounding a relatively dense inner particle. Previous investigations (6) have indicated the reaction of SO_2

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with these lime particles in the spray dryer and the baghouse tends to result in the outer layer of the particle to expand as calcium sulfite is formed. This expansion constricts the pore openings to the inner regions of the particles. Thus, the central regions of the particle may undergo little, if any, reaction and the overall raw material utilization may be significantly less than the 100% conversion present at the surface of the particle.

Although considered dry, this particulate matter does contain some surface moisture. The unreacted lime and any remaining SO_2 continue to react, although at a much slower rate, as the flue gas leaves the spray dryer and passes to the particulate collection device. This slower rate is due to the loss of liquid water from the reaction system and the passage to the gas-solid reaction regime. The evaporation of the remaining moisture in the particle occurs by diffusion of the water through these pores to the surface. The final moisture content is a function of the diffusion rates, vapor pressures, temperature differences between the particles and the flue gas, and the residence time.

Baghouse--

Although most of the liquid water is evaporated, some surface moisture remains and thus, even though the reaction is substantially curtailed, the gas-liquid reaction can continue to occur where this surface moisture is present. Therefore, the SO_2 and the available lime continue to react as the particulate-laden flue gas passes through the ductwork and into the baghouse. In the baghouse, the intimate contact between the flue gas and the alkaline filter cake provides additional time for the reaction of SO_2 and any remaining lime.

DOCUMENTATION

This manual provides the information and procedures necessary to use the model, but it does not describe in detail the concepts and mathematics upon which it is based. The lime spray dryer FGD computer model uses many of the calculations and models originally developed for and used in the earlier Shawnee FGD computer model. The design and economic premises on which the calculations are based are shown in Appendix B.

Scope of the Model

The lime spray dryer FGD computer model is based on use of lime as the alkali absorbent in a spray dryer followed by a utility-type, reverse-air baghouse and ID fan. The spray dryer vessel contains a single rotary atomizer and has a side gas exit.

The model includes all of the equipment required to treat and handle the flue gas from the boiler ID fans to the stack plenum. It also includes all of the equipment necessary to receive lime, prepare the feed slurry, and dispose of the FGD waste (and fly ash) in an environmentally acceptable manner.

The model provides for optional reheat of the gas upstream of the baghouse by blending scrubbed flue gas from the spray dryer with either (1) flue gas which bypasses the spray dryer (warm gas bypass) or (2) flue gas which bypasses the air preheater and the spray dryer (hot gas bypass). Warm and hot gas bypasses allow the spray dryer to operate at close approach-to-saturation temperatures where SO_2 removal is enhanced followed by reheat of the flue gas entering the baghouse to minimize potential corrosion problems.

Equipment size and layout configurations are based on units that range in size from 50 to 1,300 MW and for coal sulfur contents that range from 0.5 to 5.0%. Because extreme variations in equipment sizes and layout configurations can result from factors other than unit size and coal sulfur content, ranges for some of these variables have been defined as follows:

Variable	Range
Power plant	New, 50-1,300 MW
Fuel sulfur content	0.5-5%[a]
Fuel SO_2 content	1.1-9.0 lb SO_2/MBtu
SO_2 concentration	400-4,000 ppm
Excess air	0-40%
Air inleakage (boiler system)	0-20%
Approach-to-saturation temperature	15-50°F
Spray dryer residence time	5-12 sec
Number of operating spray dryers	1-10
Number of spare spray dryers	0-10
Number of spare preparation units	0-10
SO_2 removal efficiency	49-97%
Fly ash removal efficiency	1-99.9%
Baghouse pressure drop	4-8 in. water
Air-to-cloth ratio	1.5-3.0 aft^3/min/ft^2 cloth area

a. For coal sulfur levels above 2%, the model tends to underestimate the required lime stoichiometry, and hence the user should operate the model in the "force-through" mode (i.e., specifying both the lime stoichiometry and the overall SO_2 removal efficiency--see later discussion under model options).

Note: The variable ranges were established for model development purposes. Values beyond these ranges are not necessarily invalid, but the potential for error is greater when these ranges are exceeded.

Several model runs may be required to fully analyze the combined effects of individual input factors, especially if the specified ranges are exceeded. The effect of variations in inputs (such as spray dryer residence time, approach-to-saturation temperature, or alkali stoichiometry) can be assessed individually by varying one factor per model run, or the cumulative effect can be determined by varying several factors simultaneously.

LIMITATIONS

The spray dryer model is based on published information relating the overall SO_2 removal efficiency to major spray dryer design variables. These SO_2 removal equations, however, have two significant drawbacks.

The SO_2 removal equations are based on test results from pilot plants operating on flue gas with low inlet SO_2 concentrations and as a result, the SO_2 removal equation does not include correction factors for changes in the inlet SO_2 concentration. Thus, for cases where the inlet SO_2 concentration is higher than 1,000 ppm SO_2, the model will tend to calculate lime stoichiometries which are too low to achieve the specified SO_2 removal efficiency. The higher the actual inlet SO_2 concentration, the larger the error in the calculated lime stoichiometry. Thus, for medium- and high-sulfur coal applications, the user must run the model in the "force-through" mode by specifying both the lime stoichiometry and the overall SO_2 removal efficiency in order to generate a realistic design and hence economic evaluation (see lime stoichiometry option discussion).

The second problem with these SO_2 removal equations is that the equations calculate only an overall SO_2 removal efficiency; there is no breakdown of the removal into separate spray dryer and baghouse components. (Most of the SO_2 removal occurs in the spray dryer; however, a significant portion of the overall SO_2 removal may occur in the baghouse, depending on the process conditions.) Because of this limitation on the removal equation, the material balance calculations in the current model assume that all of the SO_2 removal occurs in the spray dryer.

Both of these problems with the design removal equation are expected to be corrected in a revised version of the computer model. TVA began operating a spray dryer/baghouse pilot plant at the Shawnee test facility in March 1983 as part of its overall spray dryer development program, and the data from the pilot-plant work will be used to generate more appropriate design equations (2).

The equations are also based on an 18°F approach-to-saturation temperature in the spray dryer. Simulations at other approach-to-saturation temperatures will require the user to know the lime stoichiometry necessary to achieve the overall SO_2 removal efficiency at these other approach-to-saturation temperatures. The existing model will significantly underestimate the lime stoichiometry if the simulation is not run in the "force-through" mode. Since the approach-to-saturation temperature is one of the most critical design variables with a significant impact on lime consumption, and hence process economics, the optimum approach-to-saturation temperature (18°F) for SO_2 removal has been built into the model.

Another limitation of the spray dryer model is based on the technical constraints of the spray dryer technology itself and is not the result of a lack of data. This technical constraint is the water balance in the spray dryer. The available heat in the flue gas entering the spray dryer is used to evaporate the water in the combined feed slurry and generate a relatively dry product containing <5% water. The weight percent solids in the makeup lime slurry also cannot exceed 25%. Thus, if the user specifies both a high SO_2 removal efficiency and a high-sulfur coal application, the quantity of water necessary to transport the lime to the spray dryer to achieve the high SO_2 removal efficiency may exceed the amount of water which can be evaporated in the spray dryer. The model has been designed to terminate if the user-supplied data result in a water balance problem in the spray dryer. The user can take corrective action by: (1) reducing the lime stoichiometry (and hence SO_2 removal efficiency), (2) reducing the coal sulfur level, or (3) raising the inlet flue gas temperature.

AVAILABILITY

TVA and EPA have made the necessary arrangements to make the model available to the public through TVA. Upon receipt of a written request and execution of an appropriate disclaimer, TVA will provide a copy of the model suitable for loading onto an IBM-370-compatible computer system, along with FORTRAN program listings and the documentation required to execute the model. TVA may also make a limited number of model runs based on user-supplied input data. This information allows users to analyze the capabilities of the model with a minimum amount of investigation and investment.

The model is based on the requirements and specifications of the VS FORTRAN compiler using the FORTRAN77 language. It cannot be used on systems based entirely on the FORTRAN66 language. Thus, in order to run this model, the user must have the VS FORTRAN compiler and the FORTRAN77 language available.

Model options and input variables will be added and modified as further development of the model occurs. The latest version is usually supplied to users and is typically the basis for projections made by TVA. Model and documentation availability, as well as model runs based on user-supplied input data, is subject to time, cost, and available funding limitations.

Requests for copies of the computer model, model runs to be made by TVA, or additional information should be made to the authors at the following address: Division of Energy Demonstrations and Technology, Tennessee Valley Authority, Muscle Shoals, Alabama 35661, telephone: (205) 386-2814 or (205) 386-2514.

MODEL DESCRIPTION

INPUT

The model requires a minimum of 20 lines of input. Free-form format is specified and blank spaces are required between variables except for the CASEID (line 1) and the END or NEXT variable (last line of data set) which are alphanumeric format. Individual values may be specified to the desired precision provided the total characters, including separators, do not exceed 72 per line. Additional input (i.e., more than 20 lines) is required when a user-specified operating profile is chosen instead of the built-in profiles. A detailed FORTRAN variable list of the model input is shown in Table C-1 of Appendix C and these input variables are defined in Table C-2 of Appendix C. An example input data set is shown on page D-2 in Appendix D.

These tables in Appendix C include a number of options for selecting the desired process design and controlling the model output. Some of the most important of these options are listed below along with the corresponding variable name, its location (i.e., line) in the data set, and the page number in this users manual at which the option is discussed in more detail.

Option	Variable name	Line	Page
• Print	ARRAY IPRT(I)	2-5	20
• Hot gas temperature	THG	6	23
• Warm gas temperature	TWG	6	23
• Input composition (coal vs. flue gas)	ICOMP	6	24
• Bypass reheat	IBYPAS	8	28
• Temperature of flue gas to baghouse	REHEAT	8	28
• SO_2 removal			
Lb/MBtu	IXSO2	8	29
Percentage	IREM	8	29

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Option	Variable name	Line	Page
• Approach-to-saturation temperature	TAPSAT	9	C-8
• Redundancy			
Spray dryer	NSPSD	9	35
Lime preparation	NSPREP	11	36
• Lime stoichiometry	ICASTO	11	36
• Particulate removal cost	IPART	12	42
• Number of baghouses	NTBAGH	12	42
• Air-to-cloth ratio	AC	12	47
• Revenue requirement factors	-	13	C-9
• Operating profile	IOPSCH, IYROP	14	47
• Indirect capital factors	-	15	C-10
• Landfill economic factors	-	16	57
• Other capital charge factors	-	17	58
• Retrofit factor	RETRO	19	67

Ranges for key variables to aid in establishing input data to the model are shown in Table 1.

As new options are incorporated, the required inputs are subject to change. When this occurs, the list of variables and the associated definitions will be updated and made available as necessary.

OUTPUT

The outputs of the lime spray dryer FGD computer model provide a conceptual design and process economics for a lime spray dryer/baghouse system. They consist of: (1) a detailed material balance, including flow rates, chemical compositions, and physical properties of the major streams; (2) the specifications of the spray dryer/baghouse system process design; (3) the specifications and costs of the process equipment by major processing area; (4) the design and costs for the landfill disposal area; (5) a detailed breakdown of the capital investment; (6) an itemized breakdown of both the first-year and the levelized revenue requirements for the system; and (7) an optional lifetime revenue requirement analysis showing projected costs for each year of operation, as well as lifetime cumulative and discounted costs and equivalent unit revenue requirements. The lime spray dryer FGD computer model outputs are illustrated in the example printout shown in Appendix D.

TABLE 1. VARIABLE RANGES

Variable	Range
Power plant	New, 50-1,300 MW
Fuel sulfur content	0.5-5%[a]
Approach-to-saturation temperature	15-50°F
Spray dryer residence time	5-12 sec
Number of operating spray dryers	1-10
Number of spare spray dryers	0-10
Number of spare preparation units	0-10
SO_2 removal efficiency	49-97%
Fly ash removal efficiency	1-99.9%
Baghouse pressure drop	4-8 in. water
Air-to-cloth ratio	1.5-3.0 $aft^3/min/ft^2$ cloth area

a. For coal sulfur levels above 2%, the model tends to underestimate the required lime stoichiometry, and hence the user should operate the model in the "force-through" mode (i.e., specifying both the lime stoichiometry and the overall SO_2 removal efficiency--see later discussion of this option).

Note: The variable ranges were established for model development purposes. Values beyond these ranges are not necessarily invalid, but the potential for error is greater when these ranges are exceeded.

OPTIONS

The model inputs include a number of options for selecting the desired process design and controlling the model output. Some examples of the most important options available to the user are discussed in more detail on the following pages. For illustration purposes, the appropriate input data line and variable names are shown and the particular option code is indicated. An explanation of each option and a sample output resulting from its use are provided where necessary. Unless a value of zero is specifically required, the user would be advised to avoid zero values in the input data set. If a nonzero value is inserted, the value calculated by the model will override the input value. Blank spaces are not interchangeable with zero values in the input data set.

Some user-specified input values result in the use of default values. For the options that allow defaults, the option code that must be input and the default values that are assumed are described. All model output listings used to illustrate individual options are derived from the sample computer model run shown in Appendix D. Only the variables related to options being illustrated are changed from the base case unless otherwise noted. All illustrations have been edited to show only the results affected by modification of the input data. Input data variables being illustrated are often set at their maximum value to assist the user in understanding the impact of input data modifications on system projections.

Print Options

The print options of most interest to the user are located on the fifth line of the input data set. The user may specify a total printout or selected portions of the printout using these options. The first two inputs on this line [IPRT(5) and IPRT(6)] determine whether the landfill design or cost information, respectively, is printed. If IPRT(5) is set at one, the landfill design information is printed. If IPRT(6) is set at one, the landfill cost information is printed. (These options are described in the input definition list in Table C-2 of Appendix C.)

```
Line No.     Input data

   5         1 1 0 0
                /  \
             IPRT(7) IPRT(8)
```

Print options IPRT(7) and IPRT(8) determine whether the capital investment and annual revenue requirement tables, respectively, are printed out in the short or the long form. When IPRT(7) is set to zero, only the short-form version of the capital investment summary table is printed. Similarly, when IPRT(8) is set to zero, only the short-form version of the annual revenue requirement table is printed. The short-form capital investment and annual revenue requirement table printouts are shown in Table 2 and may be compared with the long-form tables shown in the example printout in Appendix D. When print option IPRT(7) or IPRT(8) is set to one, the long-form capital investment and annual revenue requirement tables are printed, respectively.

Boiler Design Options

Material Balance Options--

Line 6 on the input data set allows the user to specify boiler design and operating conditions. The initial eight entries on line 6 affect the material balance around the boiler and the resulting flue gas composition.

TABLE 2. EXAMPLE RESULTS ILLUSTRATING SHORT-FORM CAPITAL INVESTMENT AND ANNUAL REVENUE REQUIREMENT TABLE PRINTOUTS

```
LIME SPRAY DRYER PROCESS --

BASIS: 500 MW UNIT, 1987 STARTUP

PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINUS

                                                    INVESTMENT, THOUSANDS OF 1985 DOLLARS
                              ------------------------------------------------------------------------------
                              MAT HAND FEED PREP GAS HAND SO2 ABSORB PART REM SD HAND GAS RECYCLE TOTAL        $/KW
                              -------- --------- -------- ---------- -------- ------- ----------- -----        ----
TOTAL PROCESS CAPITAL            1033.     1066.   10175.     10781.   21468.    756.        264.  45543.      91.09
TOTAL DIRECT INVESTMENT          1095.     1130.   10786.     11428.   22756.    801.       2981.  50977.     101.95
TOTAL FIXED INVESTMENT           1708.     1762.   16826.     17828.   35500.   1249.       4067.  78940.     157.88
TOTAL CAPITAL INVESTMENT         2216.     2286.   21814.     23112.   46021.   1620.       5335. 102404.     204.81
```

(Continued)

TABLE 2. (Continued)

```
LIME SPRAY DRYER PROCESS --

BASIS: 500 MW UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - 0.7% S WESTERN SUBBITUMINUS

ANNUAL OPERATION KW-HR/KW = 5500
                                               REVENUE
                                           REQUIREMENT, $
                                           --------------

SUBTOTAL RAW MATERIAL                          939000

SUBTOTAL CONVERSION COSTS                     6333700
SUBTOTAL INDIRECT COSTS                       2587100
LEVELIZED CAPITAL COSTS                      15975100
                                           ----------
FIRST YEAR ANNUAL REVENUE REQUIREMENTS 25834900
LEVELIZED ANNUAL REVENUE REQUIREMENTS  34570700

EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS = 9.39 MILLS/KWH

EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS = 12.57 MILLS/KWH
```

The first five input variables (MW, BHR, HVC, EXSAIR, and AIRINL) are involved in the flue gas composition and flow rate calculations.

```
Line No.                     Input data
   6         500 10500 8200   20    19   14.7 85 80 705 300 1
              ↓     ↓     ↓     ↓     ↓
             MW    BHR   HVC EXSAIR AIRINL
```

The boiler size is input to the model using the variable MW which has the units MW. MW can range from 50 to 1,300. The boiler heat rates (net) are specified by the variable BHR which has the units Btu/kWh. The heat rates are based on the type of coal being burned and the size and age of the unit. The as-fired heating value of the coal is specified by the variable HVC and has the units Btu/lb. Typical as-fired heating values for various coals are given in the premises (Appendix B). Variables EXSAIR and AIRINL allow the user to input the excess combustion air to the boiler and the additional inleakage of air into the flue gas in the air heater, respectively. Typical values are 20% and 19%, respectively.

The next three input variables (PRES, SULO, and ASHO) also are involved in the flue gas composition calculation.

```
Line No.                     Input data
   6         500 10500 8200 20 19 14.7 85 80 705 300 1
                                  /    /   \
                               PRES SULO ASHO
```

The atmospheric pressure is input using variable PRES and in most cases will remain constant at 14.7 lb/in^2. The percentages of the SO_2 and the fly ash generated from the combustion of the coal which pass overhead in the flue gas are provided by inputs SULO and ASHO.

Flue Gas Temperature Options--

The next two input values on line 6 refer to the flue gas temperatures in the "back end" of the boiler which can have a significant impact on the spray dryer/baghouse FGD system.

```
Line No.                     Input data
   6         500 10500 8200 20 19 14.7 85 80 705 340 1
                                          ↓   ↓
                                         THG TWG
```

Input variable THG is used to specify the temperature of the flue gas at the boiler economizer exit. (It also defines the hot gas bypass temperature--see the discussion of the reheat options later in this section.) Input variable TWG is used to specify the flue gas temperature at the air heater outlet, which defines the spray dryer inlet flue gas temperature. (It also defines the warm gas bypass temperature--see the discussion of the reheat option later in this section.) A higher spray dryer inlet temperature offers the dual benefit of (1) providing a higher reheat temperature when warm gas bypass is used and (2) allowing more water in the form of feed slurry to be added to the spray dryer. Changing the air heater outlet temperature results in minor, indirect changes in the capital investment and the revenue requirements by changing the volume of water injected into the spray dryer, and thus the flue gas rate from the spray dryer. For case variations in which the bypass option is available, changing the air heater outlet temperature results in more significant changes in the costs since the amount of flue gas bypassing the spray dryer can change dramatically. An example output showing the results of specifying a higher air heater outlet temperature (and hence higher spray dryer inlet temperature) for a bypass case is shown in Table 3.

Flue Gas Composition Input Option--

The flue gas composition input option (ICOMP) allows the user to specify the flue gas composition directly if, for example, the user has only a flue gas composition.

Line No.	Input data
6	500 10500 8200 20 19 14.7 85 80 705 300 1

```
                                           ↙
                                         ICOMP
```

The following values are used for the ICOMP option:

0 - Coal composition is specified

1 - Flue gas composition is specified

This option also allows the model to be used to estimate the costs for an FGD system for boilers fired with other fuels. [When the flue gas composition is specified directly, the variables described for line 7B (CO_2, HCl, SO_2, O_2, N_2, H_2O, etc., see Table C-2) should be used instead of line 7A.] When the flue gas composition is specified directly, the user must also input either the controlled outlet emission rate or the percentage of SO_2 removal (see discussion of SO_2 removal options later in this section). The user cannot directly specify the 1979 new source performance standards (NSPS) emission levels.

When a coal composition is specified, a "BOILER CHARACTERISTICS" section is included in the output. Example output showing the results of specifying a coal composition (input ICOMP = 0) is shown in the example printout in Appendix D. When a flue gas composition is specified, a "HOT GAS ANALYSIS" section is provided. Although the printout format is different, the capital investment and revenue requirements are essentially the same (assuming the hot gas composition is the same as would be calculated by the model). Example output showing the results of specifying a flue gas composition (input ICOMP = 1) is shown in Table 4.

TABLE 3. EXAMPLE RESULTS ILLUSTRATING SPRAY DRYER INLET WARM GAS TEMPERATURE OPTION

```
      STREAM NO.
                        *       1       :       2       :       3       :       4       :       5       :       6       :       7       :
                        *               :               :               :               :               :               :               :
     STREAM TITLE       *    COAL TO    :   TOTAL AIR   :  COMBUSTION   :    BOTTOM     :    GAS TO     :   GAS FROM    :    GAS TO     :
                        *    BOILER     :    TO AIR     :    AIR TO     :     ASH       :  ECONOMIZER   :  ECONOMIZER   :  AIR HEATER   :
                        *               :    HEATER     :    BOILER     :               :               :               :               :
                        *               :               :               :               :               :               :               :
                        *               :               :               :               :               :               :               :
                        *               :               :               :               :               :               :               :
*************************               :               :               :               :               :               :               :
   N2  (C)  LB/HR       *  (  313719.)  :    4375601.   :    3777497.   :               :    3781977.   :    3781977.   :    3781977.   :
   O2  (H)  LB/HR       *  (   22409.)  :    1318089.   :    1137919.   :               :     189653.   :     189653.   :     189653.   :
   CO2 (O)  LB/HR       *  (   68506.)  :               :               :               :    1149607.   :    1149607.   :    1149607.   :
   SO2 (N)  LB/HR       *  (    4482.)  :               :               :               :       5219.   :       5219.   :       5219.   :
   HCL (CL) LB/HR       *  (     128.)  :               :               :               :        132.   :        132.   :        132.   :
       (S)  LB/HR       *  (    3073.)  :               :               :               :               :               :               :
   H2O      LB/HR       *     187591.   :      76182.   :      65768.   :               :     453581.   :     453581.   :     453581.   :
 PARTICULATE LB/HR      *      40335.   :               :               :       8159.   :      32637.   :      32637.   :      32637.   :
                        *               :               :               :               :               :               :               :
 TOTAL      LB/HR       *     640243.   :    5769871.   :    4981184.   :       8159.   :    5612804.   :    5612804.   :    5612804.   :
 FLOW RATE              *               :               :               :               :               :               :               :
   SCFM (ATM.,60 F)     *               :    1275670.   :    1101297.   :               :    1216848.   :    1216848.   :    1216848.   :
   ACFM                 *               :    1324371.   :    2106714.   :               :    3158261.   :    2713766.   :    2713766.   :
   GAS TEMP.(DEG. F)    *               :         80.   :        535.   :               :        890.   :        700.   :        700.   :
*************************


*************************
      STREAM NO.        *       8       :       9       :      10       :      11       :      12       :      13       :      14       :
                        *               :               :               :               :               :               :               :
     STREAM TITLE       *      AIR      :    GAS TO     :   GAS FROM    :    BYPASS     :    GAS TO     :    GAS TO     :    GAS TO     :
                        *   INLEAKAGE   :    SPRAY      :    SPRAY      :               :   BAGHOUSE    :     FAN       :    STACK      :
                        *               :    DRYER      :    DRYER      :  (WARM GAS)   :               :               :               :
                        *               :               :               :               :               :               :               :
                        *               :               :               :               :               :               :               :
                        *               :               :               :               :               :               :               :
*************************               :               :               :               :               :               :               :
          N2  LB/HR     *     598104.   :    4085995.   :    4025995.   :     294085.   :    4380079.   :    4380079.   :    4380079.   .
          O2  LB/HR     *     180170.   :     344993.   :     344782.   :      24830.   :     369612.   :     369612.   :     369612.   :
         CO2  LB/HR     *               :    1072420.   :    1072322.   :      77186.   :    1149508.   :    1149508.   :    1149508.   :
         SO2  LB/HR     *               :       4869.   :       1492.   :        350.   :       1842.   :       1842.   :       1842.   :
         HCL  LB/HR     *               :        123.   :          6.   :          9.   :         15.   :         15.   :         15.   :
         H2O  LB/HR     *      10413.   :     432841.   :     711448.   :      31153.   :     742601.   :     742601.   :     742601.   :
 PARTICULATE  LB/HR     *               :      30446.   :     112581.   :       2191.   :     114772.   :        158.   :        158.   :
                        *               :               :               :               :               :               :               :
 TOTAL        LB/HR     *     788688.   :    5971684.   :    6328624.   :     429805.   :    6758428.   :    6643813.   :    6643813.   :
 FLOW RATE              *               :               :               :               :               :               :               :
   SCFM (ATM.,60 F)     *     174372.   :    1297812.   :    1395267.   :      93408.   :    1488676.   :    1488676.   :    1488676.   :
   ACFM                 *     333563.   :    1996088.   :    1653205.   :     143666.   :    1797371.   :    1797371.   :    1814578.   :
   GAS TEMP.(DEG. F)    *        535.   :        340.   :        156.   :        340.   :        168.   :        168.   :        174.   :
*************************
```

(Continued)

TABLE 3. (Continued)

```
    LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                       DISPLAY SHEET FOR YEAR=    1
                                    ANNUAL OPERATION KW-HR/KW =  5500
                                                                                         TOTAL
                                                                                        ANNUAL
                                                   ANNUAL QUANTITY        UNIT COST,$   COST,$
                                                   ---------------        -----------   ------
      DIRECT COSTS
      ------------
        RAW MATERIAL
        ------------
          LIME                                          10.0 K TONS       90.00/TON         901300
                                                                                       ----------
             SUBTOTAL RAW MATERIAL                                                          901300

        CONVERSION COSTS
        ----------------
          OPERATING LABOR AND
            SUPERVISION                              31410.0 MAN-HR       19.00/MAN-HR      596700
          LANDFILL LABOR AND
            SUPERVISION                              24960.0 MAN-HR       24.00/MAN-HR      599000
          UTILITIES
            PROCESS WATER                           186250.0 K GAL         0.16/K GAL        29800
            ELECTRICITY                           35809920.0 KWH           0.055/KWH       1969500
            DIESEL FUEL                              48260.0 GAL           1.60/GAL          77200
          MAINTENANCE
            LABOR AND MATERIAL                                                             3044800
          ANALYSES                                    5330.0 HR           26.00/HR          138600
                                                                                       ----------
             SUBTOTAL CONVERSION COSTS                                                     6455600

             SUBTOTAL DIRECT COSTS                                                         7356900

      INDIRECT COSTS
      --------------
        OVERHEADS
          PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)            2627500
                                                                                       ----------
        FIRST YEAR OPERATING AND MAINTENANCE COSTS                                         9984400
        LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                    16326400
                                                                                       ----------
           FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                         26310800

           EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)          9.57
-----------------------------------------------------------------------------------------------------------------
        LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)       18830600
        LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                    16326400
                                                                                       ----------
           LEVELIZED ANNUAL REVENUE REQUIREMENTS                                          35157000

           EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)           12.78
-----------------------------------------------------------------------------------------------------------------
        HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1760700 TONS/YR
```

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TABLE 4. EXAMPLE RESULTS ILLUSTRATING INPUT FLUE GAS COMPOSITION OPTION

```
 0.7% S WESTERN SUBBITUMINOUS 500 MW  -- 1 GAS INPUT

                                                         **** OUTPUTS ****
MATERIAL BALANCE -  COMBUSTION RELATED

********************
    STREAM NO.     *       1      :       2      :       3      :       4      :       5      :       6      :       7      :
                   *              :              :              :              :              :              :              :
  STREAM TITLE     *    COAL TO   :   TOTAL AIR  :  COMBUSTION  :    BOTTOM    :    GAS TO    :   GAS FROM   :    GAS TO    :
                   *    BOILER    :   TO AIR     :   AIR TO     :     ASH      :  ECONOMIZER  :  ECONOMIZER  :  AIR HEATER  :
                   *              :   HEATER     :   BOILER     :              :              :              :              :
                   *              :              :              :              :              :              :              :
                   *              :              :              :              :              :              :              :
********************              :              :              :              :              :              :              :
   N2  (C)   LB/HR *              :              :              :              :              :              :              :
   O2  (H)   LB/HR *              :              :              :              :              :              :              :
   CO2 (O)   LB/HR *              :              :              :              :              :              :              :
   SO2 (N)   LB/HR *              :              :              :              :              :              :              :
   HCL (CL)  LB/HR *              :              :              :              :              :              :              :
       (S)   LB/HR *              :              :              :              :              :              :              :
   H2O       LB/HR *              :              :              :              :              :              :              :
PARTICULATE  LB/HR *              :              :              :              :              :              :              :
                   *              :              :              :              :              :              :              :
TOTAL        LB/HR *              :              :              :              :              :              :              :
FLOW RATE          *              :              :              :              :              :              :              :
  SCFM (ATM.,60 F) *              :              :              :              :              :              :              :
  ACFM             *              :              :              :              :              :              :              :
********************


********************
    STREAM NO.     *       8      :       9      :      10      :      11      :      12      :      13      :      14      :
                   *              :              :              :              :              :              :              :
  STREAM TITLE     *      AIR     :    GAS TO    :   GAS FROM   :    BYPASS    :    GAS TO    :    GAS TO    :    GAS TO    :
                   *   INLEAKAGE  :    SPRAY     :    SPRAY     :              :   BAGHOUSE   :     FAN      :    STACK     :
                   *              :    DRYER     :    DRYER     :  (WARM GAS)  :              :              :              :
                   *              :              :              :              :              :              :              :
                   *              :              :              :              :              :              :              :
********************              :              :              :              :              :              :              :
         N2  LB/HR *              :   3935094.   :   3935094.   :    444975.   :   4380068.   :   4380068.   :   4380068.   :
         O2  LB/HR *              :    332252.   :    332041.   :     37571.   :    369612.   :    369612.   :    369612.   :
         CO2 LB/HR *              :   1032815.   :   1032662.   :    116789.   :   1149451.   :   1149451.   :   1149451.   :
         SO2 LB/HR *              :      4689.   :      1312.   :       530.   :      1842.   :      1842.   :      1842.   :
         HCL LB/HR *              :       119.   :         6.   :        13.   :        19.   :        19.   :        19.   :
         H2O LB/HR *              :    416856.   :    629361.   :     47137.   :    676499.   :    676499.   :    676499.   :
PARTICULATE  LB/HR *              :     29321.   :     88288.   :      3316.   :     91604.   :       158.   :       158.   :
                   *              :              :              :              :              :              :              :
TOTAL        LB/HR *              :   5751144.   :   6018763.   :    650331.   :   6669093.   :   6577646.   :   6577646.   :
FLOW RATE          *              :              :              :              :              :              :              :
  SCFM (ATM.,60 F) *              :   1249882.   :   1324111.   :    141335.   :   1465446.   :   1465446.   :   1465446.   :
  ACFM             *              :   1826252.   :   1562298.   :    206510.   :   1769325.   :   1769325.   :   1786263.   :
  GAS TEMP.(DEG. F)*              :      300.    :      154.    :      300.    :      168.    :      168.    :      174.    :
********************
```

Bypass Control and Reheat Options

Bypass Option--

An emergency bypass around the spray dryer is provided by the model for one-half of the flue gas normally scrubbed as specified in the premises (Appendix B). Only the spray dryers are bypassed, however, with the emergency bypass ducts passing around the spray dryers to reenter the system upstream of the baghouse where particulate control is still provided. If only one operating spray dryer is specified (line 9, NOPSD), then the emergency bypass is sized for all of the gas normally scrubbed instead of only one-half. When partial scrubbing/bypass (line 8, IBYPAS) is specified, the emergency bypass is sized for 50% of the gas normally scrubbed (100% of the gas normally scrubbed if only one spray dryer) plus the partial bypass normally used for the unscrubbed gas (the total cannot exceed 100%).

Line No.	Input data
8	1 200 0 0 0 0
	IBYPAS REHEAT

The following values are used for the IBYPAS option:

0 - No bypass

1 - Bypass allowed

The partial bypass option IBYPAS allows FGD systems to be designed for conditions where reheat may be obtained using flue gas bypassed around the spray dryer. The input variable IBYPAS controls the calculation of the type and amount of bypass (see reheat option discussion below). A value of "zero" specifies that there is no bypass. A value of "one" specifies that the model will calculate the bypass required. The model will calculate the flue gas bypass using the percentage of flue gas that can be bypassed (if any) and still meet the emission limit or overall SO_2 removal efficiency specified (line 8, AXSO2 or REMSO2).

Reheat Option--

The variable REHEAT specifies the flue gas temperature entering the baghouse. This option is included because of the concerns expressed by numerous utilities about the potential for corrosion in the baghouse and other downstream equipment in the spray dryer/baghouse system. The spray dryer typically operates at a close approach to the flue gas saturation temperature (18°F), and hence heat losses in the baghouse could result in condensation in the baghouse and downstream equipment. Because of the high grain loading in the flue gas between the spray dryer and the baghouse, conventional indirect steam reheat methods are not appropriate for this application.

There are two methods incorporated in this model for reheating the flue gas entering the baghouse and both involve bypassing flue gas around the spray dryer. The user has no means of specifying which method is used; the model determines the method used. The first method (in the program hierarchy) is the so-called warm gas bypass in which flue gas from the boiler air heater outlet is bypassed around the spray dryer to achieve the specified reheat temperature. (Since the flue gas being bypassed is at about 300°F, substantial quantities of flue gas must be bypassed.) After calculating the volume of flue gas to be bypassed, the model recalculates the energy balance around the spray dryer and determines if the specified SO_2 removal efficiency can be achieved. If the resulting process design is technically feasible, the model continues executing the program based on this design. If the resulting process design is not technically feasible, the second reheating method, the so-called hot gas bypass mode, is evaluated. Hot gas bypass involves bypassing flue gas around both the boiler air heater and the spray dryer. (Since the flue gas being bypassed is at about 700°F, much smaller quantities of flue gas must be bypassed using this method when compared with warm gas bypass.) After calculating the volume of flue gas to be bypassed, the model recalculates the energy balance around the spray dryer and determines if the specified SO_2 removal efficiency can be achieved. If the resulting process design is technically feasible, the model continues executing the program based on this design. If the resulting process design is not technically feasible, the program prints out the material balance for its last iteration (typically showing a negative recycle slurry flow rate to the combined feed tank) and terminates the run. If the run terminates, the user must adjust the coal composition (i.e., reduce the coal sulfur level), increase the air heater outlet temperature (TWG), reduce the required SO_2 removal efficiency, or combine several of these changes.

Once the bypass design has been selected, the model determines the appropriate ductwork lengths and diameter based on the source and the amount of bypassed gas. The model does not optimize the capital investment cost for the bypass option. An example of the effect of using a reheat temperature (entering the baghouse) of 200°F is shown in Table 5 and can be compared with the example shown in Appendix D.

SO_2 Removal Option

The model contains three methods for specifying SO_2 outlet concentrations or removal. The controlling variables are IXSO2, AXSO2, IREM, and REMSO2 on line 8 of the input data set.

Line No.	Input data
8	1 168 1 0.35 0 0
	IXSO2 AXSO2 IREM REMSO2

If the user desires to specify the controlled outlet emission in lb SO_2/MBtu from the FGD system (i.e., 1.2 lb SO_2/MBtu), IXSO2 is set equal to one and the emission level is input as AXSO2. If the user desires to specify the SO_2 removal efficiency (in percent), IREM is set equal to one and the percentage removal is input as REMSO2. When both variables IXSO2 and

TABLE 5. EXAMPLE RESULTS ILLUSTRATING BAGHOUSE INLET TEMPERATURE OPTION

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 3 -- GAS HANDLING		
1. FAN (4): INDUCED DRAFT, 465905. ACFM, 13.8-IN. STATIC HEAD, 1445.-HP	1410015.	65763.
	1410015.	65763.
AREA 4 -- SO2 ABSORPTION		
1. TANK, HEAD (4): 2.1-FT DIA. X 5.4-FT HIGH, 170. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	3004.	2503.
2. SPRAY DRYER (4): 49.1-FT DIA. X 34.8-FT STRAIGHT SIDE HEIGHT, 531915. ACFM, 60 DEGREE CONICAL HOPPER, INCLUDES 700-HP ATOMIZER, (3 OPERATING, 1 SPARE)	7052242.	945184.
	7055245.	947687.
AREA 5 -- PARTICULATE REMOVAL		
1. BAGHOUSE (2): REVERSE AIR, 931810. ACFM, 2.00 OPERATING AIR-TO-CLOTH RATIO, 10. TOTAL COMPARTMENTS PER BAGHOUSE, 8. OPERATING COMPARTMENTS PER BAGHOUSE	7315013.	12520547.
2. CONVEYOR, BAGHOUSE PARTICULATE REMOVAL (4): BELT, 18-IN. WIDE X 241.-FT LONG, 3.5-HP, 11.8 TONS/HR (TWO PER BAGHOUSE)	175297.	24196.
3. CONVEYOR, BAGHOUSE PARTICULATE COLLECTION (1): BELT, 18-IN. WIDE X 80.-FT LONG, 3.5-HP, 47.3 TONS/HR	35239.	4750.
4. ELEVATOR, BAGHOUSE PARTICULATE COLLECTION (1): CONTINUOUS BUCKET, 3.5-HP , 25.-FT LIFT, 47.3 TONS/HR	19869.	1139.
5. BIN, BAGHOUSE PARTICULATE SURGE (2): 7.-FT DIA. X 11.-FT STRAIGHT SIDE HEIGHT, COVERED, 45-DEGREE CONE HOPPER, CARBON STEEL, INCLUDES HOPPER HEATER	6270.	3880.
6. CONVEYOR, BAGHOUSE PARTICULATE DISPOSAL (1): PNUEMATIC, PRESSURE, 250.0-HP	242382.	83642.
7. SILO, PARTICULATE DISPOSAL (1): 20.-FT DIA. X 30.-FT STRAIGHT SIDE HEIGHT, 9785. FT3, CONCRETE CONSTRUCTION	33658.	60065.
8. HOPPER, PARTICULATE DISPOSAL SILO (1): 45-DEGREE CONE, CARBON STEEL	8214.	3494.
9. DUST COLLECTOR, PARTICULATE DISPOSAL SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	7843230.	12704666.

(Continued)

TABLE 5. (Continued)

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	429.	391.	1410.	7055.	7843.	412.	70.	17612.	35.22
LABOR	221.	121.	66.	948.	12705.	135.	81.	14276.	28.55
PIPING									
MATERIAL	0.	50.	0.	272.	0.	0.	0.	322.	0.64
LABOR	0.	67.	0.	95.	0.	0.	0.	162.	0.32
DUCTWORK									
MATERIAL	0.	0.	4250.	0.	0.	0.	0.	4250.	8.50
LABOR	0.	0.	3055.	0.	0.	0.	0.	3055.	6.11
FOUNDATIONS									
MATERIAL	15.	24.	54.	238.	110.	9.	5.	454.	0.91
LABOR	27.	45.	97.	427.	199.	19.	9.	823.	1.65
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	226.	4.	3.	307.	0.61
LABOR	17.	15.	0.	0.	329.	3.	1.	364.	0.73
ELECTRICAL									
MATERIAL	92.	108.	167.	85.	95.	79.	64.	691.	1.38
LABOR	51.	51.	651.	70.	39.	23.	15.	901.	1.80
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	157.	30.	9.	642.	1.28
LABOR	2.	15.	4.	40.	70.	9.	1.	141.	0.28
BUILDINGS									
MATERIAL	34.	0.	0.	547.	0.	0.	0.	581.	1.16
LABOR	14.	0.	0.	223.	0.	0.	0.	238.	0.48
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	49.	53.	444.	634.	632.	40.	11.	1864.	3.73
TOTAL PROCESS CAPITAL	1031.	1078.	10238.	10896.	22405.	764.	269.	46682.	93.36
SERVICES AND MISCELLANEOUS (6.0 %)	62.	65.	614.	654.	1344.	46.	16.	2801.	5.60
TOTAL DIRECT PROCESS INVESTMENT	1093.	1143.	10852.	11550.	23749.	809.	286.	49483.	98.97
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2005.	2005.	4.01
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	65.	65.	0.13
TOTAL DIRECT INVESTMENT	1093.	1143.	10852.	11550.	23749.	809.	2986.	52183.	104.37
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	77.	80.	760.	809.	1662.	57.	20.	3464.	6.93
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	22.	23.	217.	231.	475.	16.	6.	990.	1.98
CONSTRUCTION EXPENSES (16.0 %)	175.	183.	1736.	1848.	3800.	130.	46.	7917.	15.83
CONTRACTOR FEES (5.0 %)	55.	57.	543.	578.	1187.	40.	14.	2474.	4.95
CONTINGENCY (20.0 %)	284.	297.	2821.	3003.	6175.	210.	74.	12866.	25.73
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	929.	929.	1.86
TOTAL FIXED INVESTMENT	1706.	1783.	16929.	18018.	37049.	1263.	4074.	80822.	161.64
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	171.	178.	1693.	1802.	3705.	126.	45.	7719.	15.44
INTEREST DURING CONSTRUCTION (15.6 %)	266.	278.	2641.	2811.	5780.	197.	636.	12608.	25.22
ROYALTIES (1.0 %)	10.	11.	102.	109.	224.	8.	3.	467.	0.93
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	63.	66.	624.	664.	1365.	47.	172.	3000.	6.00
TOTAL CAPITAL INVESTMENT	2217.	2318.	21992.	23406.	48126.	1641.	5356.	105056.	210.11

(Continued)

TABLE 5. (Continued)

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

  PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                         DISPLAY SHEET FOR YEAR=     1
                                        ANNUAL OPERATION KW-HR/KW =  5500
                                                                                        TOTAL
                                                  ANNUAL QUANTITY      UNIT COST,$      ANNUAL
                                                  ---------------      -----------      COST,$
       DIRECT COSTS                                                                     ------
       ------------
         RAW MATERIAL
         ------------
           LIME                                     10.4 K TONS        90.00/TON         932000
                                                                                       ----------
              SUBTOTAL RAW MATERIAL                                                      932000

         CONVERSION COSTS
         ----------------
           OPERATING LABOR AND
             SUPERVISION                          31410.0 MAN-HR       19.00/MAN-HR      596700
           LANDFILL LABOR AND
             SUPERVISION                          24960.0 MAN-HR       24.00/MAN-HR      599000
           UTILITIES
             BOILER HEAT LOSS                    330400.0 MBTU          5.30/MBTU       1751100
             PROCESS WATER                       148780.0 K GAL         0.16/K GAL        23800
             ELECTRICITY                       36161900.0 KWH           0.055/KWH       1988900
             DIESEL FUEL                          48280.0 GAL           1.60/GAL          77200
           MAINTENANCE
             LABOR AND MATERIAL                                                         3050000
           ANALYSES                                5330.0 HR           26.00/HR          138600
                                                                                       ----------
              SUBTOTAL CONVERSION COSTS                                                 8225300

              SUBTOTAL DIRECT COSTS                                                     9157300

       INDIRECT COSTS
       --------------
         OVERHEADS
           PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)         2630600
                                                                                       ----------
         FIRST YEAR OPERATING AND MAINTENANCE COSTS                                    11787900
         LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                16388800
                                                                                       ----------
            FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                     28176700

            EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)     10.25
---------------------------------------------------------------------------------------------------------------
         LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)   22232000
         LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                16388800
                                                                                       ----------
            LEVELIZED ANNUAL REVENUE REQUIREMENTS                                      38620800

            EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)      14.04
---------------------------------------------------------------------------------------------------------------
         HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1760700 TONS/YR
```

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IREM are zero, the model will calculate the SO_2 removal efficiency required to meet the 1979 NSPS. Figure 1 illustrates the relationship between the SO_2 content of the raw coal and the controlled outlet emission levels in the 1979 NSPS used in the model. If both IXSO2 and IREM are specified as one, the program defaults to IXSO2 = 1 and IREM = 0, a warning message is printed, and the program is executed under these conditions. To avoid this error, the user must set either IXSO2 or IREM = 1 but not both. A summary of the input options is shown below:

IXSO2 = 0	SO_2 removal is based on either IREM or NSPS
IXSO2 = 1	The controlled outlet emission (in lb SO_2/MBtu) is input as AXSO2
IREM = 0	SO_2 removal is based on either IXSO2 or NSPS
IREM = 1	The percent SO_2 removal is input as REMSO2

The capital investment and revenue requirements are essentially unaffected by the expression of the emission limit in alternate (but equivalent) units such as percent or lb SO_2/MBtu.

An important concept related to SO_2 removal calculations in the model should be emphasized here. The SO_2 removal options are based on long-term average removals. When sizing an FGD facility, the raw material-handling, the feed preparation, the SO_2 absorption, and the baghouse particulate collection areas should be based on the maximum sulfur content of the coal rather than the long-term average. The waste disposal landfill, however, should be sized on the long-term average sulfur content of the coal. This can be done by entering the weight percent sulfur as the maximum expected and then using the waste disposal capacity factor (line 16, SDCAP) to adjust the total amount of waste generated back to the equivalent long-term average amount. This option is discussed in greater detail later in this report.

Waste Composition Option

The waste composition option allows the user to specify the composition of the waste stream to the landfill and is located on line 9 of the input data set.

Line No.	Input data
9	3 1 75 66 25 18 10 2

SO4SPL PARSPL SO3OX

The variable SO4SPL is used to specify the portion of the total $CaSO_4 \cdot 2H_2O$ which is collected in the spray dryer and exits through the discharge hopper in the absorber. This value is assumed to be relatively high because the $CaSO_4 \cdot 2H_2O$ particles tend to be relatively large, and thus are preferentially collected in the spray dryer. In the example case, a value of 75% is specified.

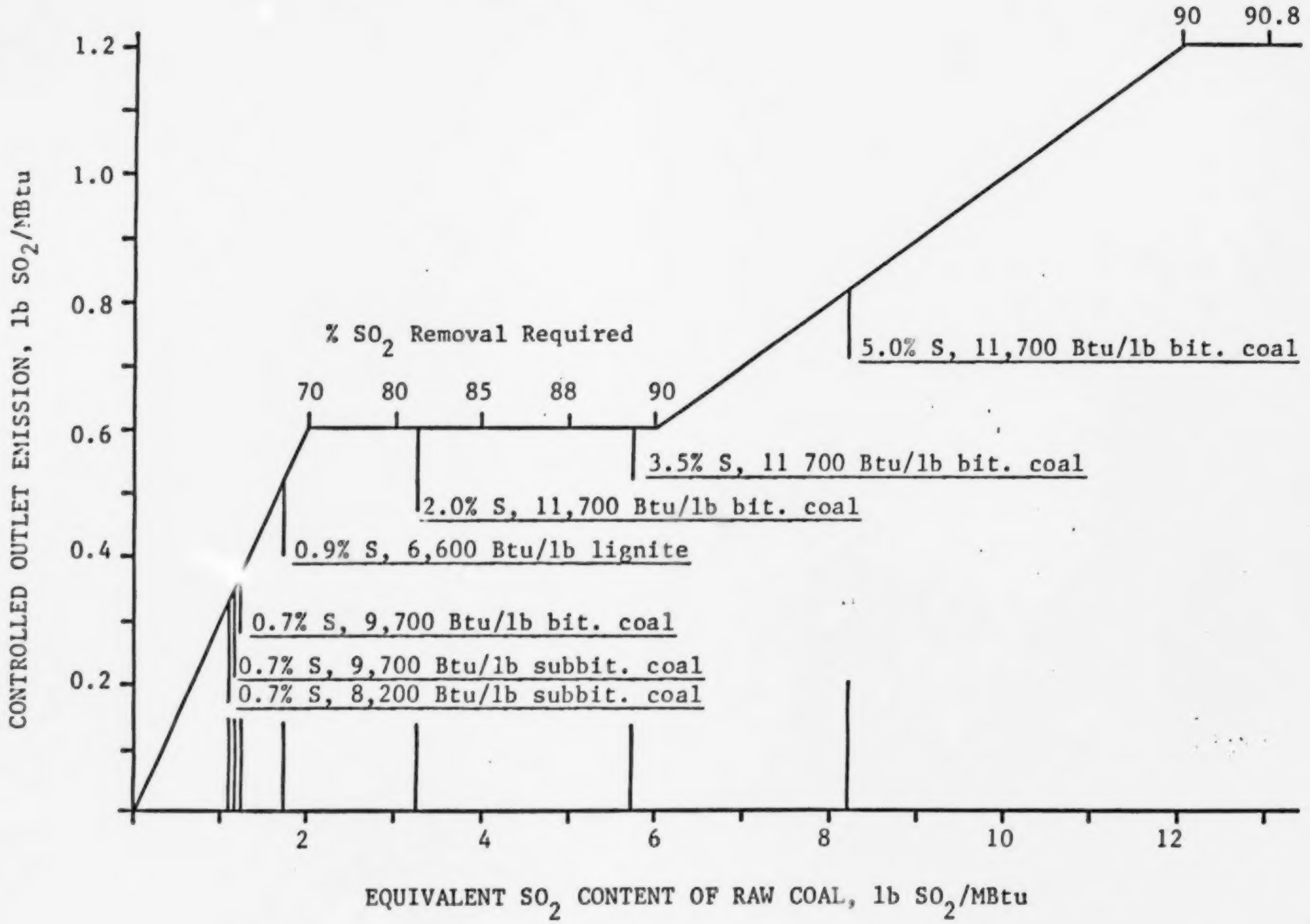

Figure 1. Controlled SO$_2$ emission requirements for 1979 NSPS. Premise coals, shown underlined, are based on premise boiler conditions.

The variable PARSPL is used to designate the percentage by weight of the particulate matter (other than $CaSO_4 \cdot 2H_2O$) which is entrained in the flue gas leaving the spray dryer and passes to the baghouse (the percentage of the particulate matter which is collected in the spray dryer hopper is calculated as 100-PARSPL). A value of 66% is used in the example case in Appendix D. Hence, the conditions specified in the example case spray dryer/baghouse FGD system result in the spray dryer waste stream being enriched in $CaSO_4 \cdot 2H_2O$ in comparison with the baghouse solids.

Oxidation of $CaSO_3 \cdot 1/2H_2O$ to $CaSO_4 \cdot 2H_2O$ within the spray dryer absorber is specified by SO3OX. A value of 25% is shown for the example case and is typical of the degree of oxidation encountered for medium- to high-sulfur coal applications. Although higher oxidation levels may result in a more environmentally stable material for landfill, the degree of oxidation is not an independent variable because absorber conditions inhibit oxidation and the formation of $CaSO_4 \cdot 2H_2O$. However, whether the waste product is predominately $CaSO_3 \cdot 1/2H_2O$ or $CaSO_4 \cdot 2H_2O$ has little effect on the operation of the computer model. There are only minor differences in the landfill site and process pipe sizing for the two waste products, resulting in minimal capital investment and revenue requirement differences.

Lime Composition Option

The lime composition option allows the user to tailor both the lime quality and the slaker efficiency [i.e., the conversion of the CaO in the lime to $Ca(OH)_2$ in the lime slurry] to the specific application. The lime specification variables (WPCAO, WPINER, WPH2OL, and WPMGOL) are defined in Table C-2 of Appendix C.

Line No.	Input data
10	95 4.85 5.0 0.15 100 WPCAO WPINER WPH2OL WPMGOL SLKEFF

The slaking efficiency is input using variable SLKEFF. Slaking efficiency is primarily dependent on the lime quality, but other factors can have an effect. Typically, a value of 98-100% can be obtained. A high value results in smaller equipment and a lower lime consumption, ultimately resulting in lower investment costs and revenue requirements.

Spare Equipment Option

Spare equipment can be specified in the SO_2 absorption area and the feed preparation area. (The spare units are identical to the operating units.) The controlling input variables are NSPSD and NSPREP on lines 9 and 11 of the input data set.

```
Line No.        Input data

   9       3    0    75 66 25 18 10 2
                |
              NSPSD
```

```
Line No.       Input data

   11          0 0 0 0 25.0 23.0
                    \
                   NSPREP
```

NSPSD indicates the number of spare spray dryers. NSPREP specifies the number of spare preparation units (feed conveyors, feeders, and slakers) and may be given any realistic value--0, 1, 2, 3. The equipment list in the example case in Appendix D shows the output for a system which includes a spare preparation unit and a spare spray dryer. For comparison, Table 6 shows the similar output for a system without any spares.

Lime Stoichiometry Option

The lime stoichiometry for the spray dryer/baghouse system is defined as mols $Ca(OH)_2$/mol (SO_2 + 2HCl) in the boiler economizer exit gas. [Note that this definition is different from the stoichiometry for wet FGD systems. In wet scrubbing, the stoichiometry is usually defined as mols of absorbent/mol of (SO_2 + 2HCl) absorbed; whereas, the stoichiometry for the spray dryer/baghouse system is defined as mols of absorbent/mol of (SO_2 + 2HCl) in the boiler economizer exit gas.] The lime stoichiometry can be either calculated by the model or input by the user, depending on the data input to the model on line 11.

```
Line No.        Input data

   11          0    1.4 1 0 25.0 23.0
               |     \
            ICASTO CAOSTO
```

The lime stoichiometry will be calculated by the model when ICASTO = 0. This calculated value will be based on equations generated to describe a low-sulfur coal application and hence, will tend to underestimate lime stoichiometries for medium- and high-sulfur coals. Alternatively, if ICASTO = 1, the model is run with the lime stoichiometry specified in the input data set as CAOSTO. The SO_2 removal efficiency will still be calculated based on the design equation in the model relating lime stoichiometry, approach-to-saturation temperature, and SO_2 removal efficiency. For medium- and high-sulfur coal applications where this basic design equation introduces substantial errors in the required lime stoichiometry (or SO_2 removal efficiency), the user may desire to run the model in the "force-through" mode. In the force-through mode, the user specifies the lime stoichiometry using ICASTO and CAOSTO and also specifies either the controlled outlet emission or the SO_2

TABLE 6. EXAMPLE RESULTS ILLUSTRATING NO SPARE EQUIPMENT

ITEM (QUANTITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 1 -- MATERIAL HANDLING		
1. CAR SHAKER AND CRANE (1): TOP MOUNTING WITH CRANE, 20.0-HP SHAKER, 7.5-HP HOIST	85232.	14392.
2. CAR PULLER (1): 25-HP PULLER, 5.0-HP RETURN	70391.	21586.
3. HOPPER, LIME UNLOADING (1): 16-FT DIA. X 10-FT STRAIGHT SIDE, CARBON STEEL 60-DEGREE CONE BOTTOM, INCLUDES 6-IN. SQUARE GRATING	16566.	6837.
4. FEEDER, LIME UNLOADING (1): VIBRATING PAN, 3.5-HP, 100 TONS/HR, CARBON STEEL	6987.	588.
5. CONVEYOR, LIME UNLOADING (1): BELT, 36-IN. WIDE X 20-FT LONG, 5.0-HP, 100 TONS/HR	11490.	1639.
6. ELEVATOR, LIME UNLOADING (1): CONTINUOUS BUCKET, 25.0-HP, 92.-FT LIFT, 100 TONS/HR	45613.	3778.
7. SILO, LIME STORAGE (1): 35.-FT DIA. X 52.-FT STRAIGHT SIDE HEIGHT, 49667. FT3, CONCRETE CONSTRUCTION	79051.	142664.
8. HOPPER, LIME STORAGE SILO (1): 60-DEGREE CONE, CARBON STEEL	12210.	9255.
9. FEEDER, RECLAIM (1): VIBRATING PAN, 3.5-HP, 1.9 TONS/HR	5174.	452.
10. CONVEYOR, RECLAIM (1): BELT, 18-IN. WIDE X 110.-FT LONG, 5.0-HP, 1.9 TONS/HR	25518.	3595.
11. ELEVATOR, RECLAIM (1): CONTINUOUS BUCKET, 1.0-HP, 32.-FT LIFT, 1.9 TONS/HR	35452.	2543.
12. BIN, LIME FEED (1): 11.-FT DIA. X 17.-FT STRAIGHT SIDE HEIGHT, COVERED, 60-DEGREE CONE HOPPER, CARBON STEEL	6581.	4403.
13. DUST COLLECTOR, LIME UNLOADING PIT (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN, INCLUDES DUST HOOD	10862.	5922.
14. DUST COLLECTOR, LIME UNLOADING PIT (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	----------	----------
	418419.	220614.

(Continued)

TABLE 6. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 2 -- FEED PREPARATION		
1. FEEDER, LIME FEED BIN (1): BIN ACTIVATOR, 6-FT DIAMETER, 2.0-HP	13013.	1480.
2. CONVEYOR, LIME FEED BIN (1): SCREW, 12-IN. DIA. X 12-FT LONG, 1.0-HP, 1.9 TONS/HR	6004.	848.
3. SLAKER (1): BALL-MILL TYPE, 31.-HP, 1.9 TONS/HR INCLUDES CLASSIFIER	54583.	8663.
4. TANK, SLAKER PRODUCT (1): 14.1-FT DIA. X 14.1-FT HIGH, 16518. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	11291.	9421.
5. AGITATOR, SLAKER PRODUCT TANK (1): 10.0-HP	11739.	972.
6. PUMP, SLAKER PRODUCT TANK (3): CENTRIFUGAL, 16. GPM, 1.0-HP, CARBON STEEL, NEOPRENE LINED (2 OPERATING, 1 SPARE)	7046.	1017.
7. FEEDER, SPRAY DRYER RECYCLE SILO (1): SCREW, 19.-IN. DIA. X 20-FT LONG, 5.0-HP, 22.7 TONS/HR	13659.	2315.
8. FEEDER, BAGHOUSE RECYCLE SILO (1): SCREW, 20.-IN. DIA. X 20-FT LONG, 5.0-HP, 25.4 TONS/HR	14706.	2493.
9. TANK, RECYCLE SLURRY (1): 42.3-FT DIA. X 21.2-FT HIGH, 222640. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	68210.	56245.
10. AGITATOR, RECYCLE SLURRY TANK (1): 25.0-HP	65790.	5449.
11. PUMP, RECYCLE SLURRY TANK (3): CENTRIFUGAL, 211. GPM, 10.0-HP, CARBON STEEL, NEOPRENE LINED (2 OPERATING, 1 SPARE)	12238.	4748.
12. TANK, COMBINED FEED (1): 17.2-FT DIA. X 8.6-FT HIGH, 14947. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	9611.	8035.
13. AGITATOR, COMBINED FEED TANK (1): 3.5-HP	11042.	915.
14. PUMP, COMBINED FEED TANK (2): CENTRIFUGAL, 588. GPM, 20.0-HP, CARBON STEEL, NEOPRENE LINED (1 OPERATING, 1 SPARE)	12819.	4957.
	311749.	107557.

(Continued)

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TABLE 6. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 3 -- GAS HANDLING		
1. FAN (4): INDUCED DRAFT, 442333. ACFM, 13.8-IN. STATIC HEAD, 1372.-HP	1371901.	63825.
	1371901.	63825.
AREA 4 -- SO2 ABSORPTION		
1. TANK, HEAD (3): 2.3-FT DIA. X 6.9-FT HIGH, 216. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	2645.	2204.
2. SPRAY DRYER (3): 48.7-FT DIA. X 34.6-FT STRAIGHT SIDE HEIGHT, 520768. ACFM, 60 DEGREE CONICAL HOPPER, INCLUDES 700-HP ATOMIZER, (3 OPERATING, 0 SPARE)	6028833.	701926.
	6031477.	704130.
AREA 5 -- PARTICULATE REMOVAL		
1. BAGHOUSE (2): REVERSE AIR, 884665. ACFM, 2.00 OPERATING AIR-TO-CLOTH RATIO, 10. TOTAL COMPARTMENTS PER BAGHOUSE, 8. OPERATING COMPARTMENTS PER BAGHOUSE	6916993.	12061130.
2. CONVEYOR, BAGHOUSE PARTICULATE REMOVAL (4): BELT, 18-IN. WIDE X 235.-FT LONG, 3.5-HP, 11.4 TONS/HR (TWO PER BAGHOUSE)	171761.	23661.
3. CONVEYOR, BAGHOUSE PARTICULATE COLLECTION (1): BELT, 18-IN. WIDE X 78.-FT LONG, 3.5-HP, 45.7 TONS/HR	34649.	4661.
4. ELEVATOR, BAGHOUSE PARTICULATE COLLECTION (1): CONTINUOUS BUCKET, 3.5-HP , 25.-FT LIFT, 45.7 TONS/HR	19800.	1135.
5. BIN, BAGHOUSE PARTICULATE SURGE (2): 7.-FT DIA. X 11.-FT STRAIGHT SIDE HEIGHT, COVERED, 45-DEGREE CONE HOPPER, CARBON STEEL, INCLUDES HOPPER HEATER	6149.	3793.
6. CONVEYOR, BAGHOUSE PARTICULATE DISPOSAL (1): PNUEMATIC, PRESSURE, 250.0-HP	234281.	80846.
7. SILO, PARTICULATE DISPOSAL (1): 20.-FT DIA. X 30.-FT STRAIGHT SIDE HEIGHT, 9795. FT3, CONCRETE CONSTRUCTION	33678.	60099.
8. HOPPER, PARTICULATE DISPOSAL SILO (1): 45-DEGREE CONE, CARBON STEEL	8217.	3496.
9. DUST COLLECTOR, PARTICULATE DISPOSAL SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	7432817.	12241778.

(Continued)

TABLE 6. (Continued)

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	418.	312.	1372.	6031.	7433.	357.	68.	15992.	31.98
LABOR	221.	108.	64.	704.	12242.	129.	78.	13544.	27.09
PIPING									
MATERIAL	0.	47.	0.	213.	0.	0.	0.	260.	0.52
LABOR	0.	63.	0.	80.	0.	0.	0.	144.	0.29
DUCTWORK									
MATERIAL	0.	0.	3858.	0.	0.	0.	0.	3858.	7.72
LABOR	0.	0.	2590.	0.	0.	0.	0.	2590.	5.18
FOUNDATIONS									
MATERIAL	15.	21.	51.	178.	107.	8.	5.	385.	0.77
LABOR	27.	40.	92.	319.	194.	18.	9.	699.	1.40
STRUCTURAL									
MATERIAL	61.	9.	0.	0.	214.	4.	3.	291.	0.58
LABOR	17.	8.	0.	0.	318.	3.	1.	346.	0.69
ELECTRICAL									
MATERIAL	92.	101.	158.	79.	93.	79.	64.	666.	1.33
LABOR	51.	47.	568.	57.	38.	23.	15.	799.	1.60
INSTRUMENTATION									
MATERIAL	10.	105.	40.	201.	157.	30.	9.	552.	1.10
LABOR	1.	12.	4.	31.	70.	9.	1.	128.	0.26
BUILDINGS									
MATERIAL	34.	0.	0.	412.	0.	0.	0.	446.	0.89
LABOR	14.	0.	0.	167.	0.	0.	0.	181.	0.36
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	47.	45.	411.	534.	600.	36.	11.	1684.	3.37
TOTAL PROCESS CAPITAL	1008.	918.	9208.	9007.	21465.	695.	264.	42565.	85.13
SERVICES AND MISCELLANEOUS (6.0 %)	60.	55.	552.	540.	1288.	42.	16.	2554.	5.11
TOTAL DIRECT PROCESS INVESTMENT	1068.	974.	9760.	9547.	22753.	737.	280.	45119.	90.24
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2006.	2006.	4.01
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	65.	65.	0.13
TOTAL DIRECT INVESTMENT	1068.	974.	9760.	9547.	22753.	737.	2981.	47820.	95.64
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	75.	68.	683.	668.	1593.	52.	20.	3158.	6.32
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	21.	19.	195.	191.	455.	15.	6.	902.	1.80
CONSTRUCTION EXPENSES (16.0 %)	171.	156.	1562.	1528.	3640.	118.	45.	7219.	14.44
CONTRACTOR FEES (5.0 %)	53.	49.	488.	477.	1138.	37.	14.	2256.	4.51
CONTINGENCY (20.0 %)	278.	253.	2538.	2482.	5916.	192.	73.	11731.	23.46
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	929.	929.	1.86
TOTAL FIXED INVESTMENT	1666.	1519.	15226.	14894.	35494.	1150.	4067.	74015.	148.03
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	167.	152.	1523.	1489.	3549.	115.	44.	7038.	14.08
INTEREST DURING CONSTRUCTION (15.6 %)	260.	237.	2375.	2323.	5537.	179.	634.	11546.	23.09
ROYALTIES (1.0 %)	10.	9.	92.	90.	215.	7.	3.	426.	0.85
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	58.	53.	529.	517.	1232.	40.	161.	2590.	5.18
TOTAL CAPITAL INVESTMENT	2162.	1971.	19748.	19316.	46031.	1491.	5337.	96055.	192.11

(Continued)

TABLE 6. (Continued)

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                   DISPLAY SHEET FOR YEAR=     1
                                  ANNUAL OPERATION KW-HR/KW =  5500
                                                                                  TOTAL
                                                                                  ANNUAL
                                              ANNUAL QUANTITY       UNIT COST,$   COST,$
                                              ---------------       -----------   ------
          DIRECT COSTS
          ------------
            RAW MATERIAL
            ------------
              LIME                              10.4 K TONS        90.00/TON         939000
                                                                                 ----------
                 SUBTOTAL RAW MATERIAL                                               939000

            CONVERSION COSTS
            ----------------
              OPERATING LABOR AND
                SUPERVISION                  31410.0 MAN-HR      19.00/MAN-HR        596700
              LANDFILL LABOR AND
                SUPERVISION                  24960.0 MAN-HR      24.00/MAN-HR        599000
              UTILITIES
                PROCESS WATER               142670.0 K GAL        0.16/K GAL          22800
                ELECTRICITY               34882740.0 KWH          0.055/KWH         1918600
                DIESEL FUEL                  48280.0 GAL          1.60/GAL            77300
              MAINTENANCE
                LABOR AND MATERIAL                                                  2788200
              ANALYSES                        5330.0 HR          26.00/HR            138600
                                                                                 ----------
                 SUBTOTAL CONVERSION COSTS                                          6141200

                 SUBTOTAL DIRECT COSTS                                              7080200

          INDIRECT COSTS
          --------------
            OVERHEADS
              PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)  2473500
                                                                                 ----------
            FIRST YEAR OPERATING AND MAINTENANCE COSTS                              9553700
            LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)         14984700
                                                                                 ----------
              FIRST YEAR ANNUAL REVENUE REQUIREMENTS                               24538400

              EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)    8.92
----------------------------------------------------------------------------------------------------------------
            LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)   18018300
            LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)              14984700
                                                                                      ----------
              LEVELIZED ANNUAL REVENUE REQUIREMENTS                                     33003000

              EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)  12.00
----------------------------------------------------------------------------------------------------------------
            HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1760700 TONS/YR
```

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removal efficiency. Under these conditions, the basic design equation is bypassed and the FGD system is designed based on the user-specified conditions.

ICASTO = 0	Lime stoichiometry is calculated by the model and the value of CAOSTO is ignored.
ICASTO = 1	Lime stoichiometry is input by the user and the model uses the value of CAOSTO.

Example output showing the results of specifying lime stoichiometry is shown in Table 7.

Particulate Removal Cost Option

Under some conditions (such as comparing FGD alternatives), the user may desire to exclude the costs for particulate removal and disposal from the spray dryer/baghouse system. This can be accomplished by using the input variable IPART on line 12 in the data set.

```
Line No.         Input data

  12          0 1 6 0.8 0.75 2.0 10
              |
              v
            IPART
```

The particulate removal cost option IPART allows the user to choose whether the spray dryer/baghouse system economics include the investment and operating costs for particulate removal and handling equipment and fly ash disposal. One of the following values must be specified.

0 - Particulate removal costs are excluded

1 - Particulate removal costs are included

It should be noted that only the economics of the FGD system are affected by using this option. The material balance is calculated as normal (i.e., to meet the required particulate removal). The equipment list is displayed as usual except that the particulate removal area is deleted. Example output showing the results of excluding the particulate removal cost is shown in Table 8.

Baghouse Design Option

The design of the reverse-air baghouse can be modified somewhat using the variables on line 12 of the input data set.

```
Line No.              Input data

  12            1 1 6 0.8 0.75 1.5 10
                 /   \      \    \   \
            NTBAGN BHPRES BGCOST AC BAGCOM
```

TABLE 7. EXAMPLE RESULTS ILLUSTRATING USER SPECIFICATION OF LIME STOICHIOMETRY

0.7% S WESTERN SUBBITUMINOUS 500 MW 00610029

MATERIAL BALANCE - DFGD PROCESS RELATED

STREAM NO.	15	16	17	18	19	20	21
STREAM TITLE	LIME TO SLAKER	WATER TO SLAKER	INERTS TO DISPOSAL	SLAKED LIME TO COMBINED FEED TANK	PARTICULATES REMOVED BY SPRAY DRYER	SPRAY DRYER PARTICULATES TO DISPOSAL SILO	SPRAY DRYER PARTICULATES TO RECYCLE SILO
CASO4•2(H2O) LB/HR					13495.	0.	13495.
CASO3•1/2(H2O) LB/HR					3843.	0.	3843.
CACO3 LB/HR					2310.	0.	2310.
CACL2 LB/HR					129.	0.	129.
CA(OH)2 LB/HR				8566.	1710.	0.	1710.
CAO LB/HR	6483.						
MGO LB/HR	10.			10.	8.	0.	8.
ASH (INERTS) LB/HR	(331.)		(331.)	(0.)	23300.	0.	23300.
H2O LB/HR	341.	27469.		25728.			
TOTAL LB/HR	7166.	27469.	331.	34303.	44794.	0.	44794.
GPM		55.		59.			
PERCENT SOLIDS		0.0		25.0			
SPECIFIC GRAVITY		1.000		1.161			

STREAM NO.	22	23	24	25	26	27	28
STREAM TITLE	TOTAL BAGHOUSE PARTICULATES	BAGHOUSE PARTICULATES TO DISPOSAL SILO	BAGHOUSE PARTICULATES TO RECYCLE SILO	TOTAL PARTICULATES TO LANDFILL	WATER FOR RECYCLE SLURRY	RECYCLE SLURRY TO COMBINED FEED TANK	COMBINED FEED SLURRY TO SPRAY DRYER
CASO4•2(H2O) LB/HR	4490.	2261.	2229.	2261.		15724.	20441.
CASO3•1/2(H2O) LB/HR	10105.	5089.	5016.	5089.		8859.	11516.
CACO3 LB/HR	6075.	3060.	3016.	3060.		5326.	6924.
CACL2 LB/HR	339.	170.	168.	170.		297.	386.
CA(OH)2 LB/HR	4497.	2265.	2232.	2265.		3942.	16260.
CAO LB/HR							
MGO LB/HR	20.	10.	10.	10.		18.	36.
ASH (INERTS) LB/HR	64583.	32524.	32059.	32855.		55359.	71966.
H2O LB/HR					166259.	166259.	249583.
TOTAL LB/HR	90110.	45380.	44730.	45711.	166259.	255784.	377113.
GPM					332.	392.	586.
PERCENT SOLIDS					0.0	35.0	33.8
SPECIFIC GRAVITY					1.000	1.304	1.286

(Continued)

TABLE 7. (Continued)

```
    LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                               DISPLAY SHEET FOR YEAR=    1
                                            ANNUAL OPERATION KW-HR/KW =  5500
                                                                                 TOTAL
                                                                                 ANNUAL
                                                ANNUAL QUANTITY     UNIT COST,$   COST,$
                                                ---------------     -----------   ------
     DIRECT COSTS
     ------------
       RAW MATERIAL
       ------------
         LIME                                        19.7 K TONS      90.00/TON      1773600
                                                                                  ----------
            SUBTOTAL RAW MATERIAL                                                    1773600

       CONVERSION COSTS
       ----------------
         OPERATING LABOR AND
           SUPERVISION                            31410.0 MAN-HR    19.00/MAN-HR     596700
         LANDFILL LABOR AND
           SUPERVISION                            24960.0 MAN-HR    24.00/MAN-HR     599000
         UTILITIES
           PROCESS WATER                         143130.0 K GAL      0.16/K GAL       22900
           ELECTRICITY                         35120270.0 KWH        0.055/KWH      1931600
           DIESEL FUEL                            69120.0 GAL        1.60/GAL        110600
         MAINTENANCE
           LABOR AND MATERIAL                                                       3012700
         ANALYSES                                  5330.0 HR        26.00/HR         138600
                                                                                  ----------
            SUBTOTAL CONVERSION COSTS                                                6412100

            SUBTOTAL DIRECT COSTS                                                    8185700

     INDIRECT COSTS
     --------------
       OVERHEADS
         PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)        2608200
                                                                                  ----------
       FIRST YEAR OPERATING AND MAINTENANCE COSTS                                   10793900
       LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)               16201900
                                                                                  ----------
          FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                    26995800

          EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)    9.82
-----------------------------------------------------------------------------------------------------------
       LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)  20357300
       LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)               16201900
                                                                                  ----------
          LEVELIZED ANNUAL REVENUE REQUIREMENTS                                     36559200

          EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)     13.29
-----------------------------------------------------------------------------------------------------------
       HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1760700 TONS/YR
```

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TABLE 8. EXAMPLE RESULTS ILLUSTRATING EXCLUSION OF PARTICULATE REMOVAL COSTS

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	430.	385.	1146.	6978.	0.	406.	68.	9414.	18.83
LABOR	222.	119.	54.	938.	0.	132.	78.	1543.	3.09
PIPING									
MATERIAL	0.	49.	0.	265.	0.	0.	0.	314.	0.63
LABOR	0.	66.	0.	94.	0.	0.	0.	160.	0.32
DUCTWORK									
MATERIAL	0.	0.	4056.	0.	0.	0.	0.	4056.	8.11
LABOR	0.	0.	2708.	0.	0.	0.	0.	2708.	5.42
FOUNDATIONS									
MATERIAL	15.	23.	51.	235.	0.	8.	5.	338.	0.68
LABOR	27.	44.	92.	422.	0.	19.	9.	613.	1.23
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	0.	4.	3.	81.	0.16
LABOR	17.	15.	0.	0.	0.	3.	1.	35.	0.07
ELECTRICAL									
MATERIAL	92.	108.	128.	85.	0.	79.	64.	556.	1.11
LABOR	51.	51.	422.	70.	0.	23.	15.	634.	1.27
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	0.	30.	9.	485.	0.97
LABOR	2.	15.	4.	40.	0.	9.	1.	71.	0.14
BUILDINGS									
MATERIAL	34.	0.	0.	541.	0.	0.	0.	575.	1.15
LABOR	14.	0.	0.	221.	0.	0.	0.	235.	0.47
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	49.	53.	407.	627.	0.	40.	11.	1186.	2.37
TOTAL PROCESS CAPITAL	1033.	1046.	9108.	10780.	0.	754.	264.	23005.	46.01
SERVICES AND MISCELLANEOUS (6.0 %)	62.	64.	546.	647.	0.	45.	16.	1380.	2.76
TOTAL DIRECT PROCESS INVESTMENT	1095.	1130.	9655.	11427.	0.	799.	280.	24385.	48.77
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	412.	412.	0.82
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	757.	757.	1.51
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	40.	40.	0.08
TOTAL DIRECT INVESTMENT	1095.	1130.	9655.	11427.	0.	799.	1489.	25594.	51.19
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	77.	79.	676.	800.	0.	56.	20.	1707.	3.41
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	22.	23.	193.	229.	0.	16.	6.	488.	0.98
CONSTRUCTION EXPENSES (16.0 %)	175.	181.	1545.	1828.	0.	128.	45.	3902.	7.80
CONTRACTOR FEES (5.0 %)	55.	56.	483.	571.	0.	40.	14.	1219.	2.44
CONTINGENCY (20.0 %)	285.	294.	2510.	2971.	0.	208.	73.	6340.	12.68
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	389.	389.	0.78
TOTAL FIXED INVESTMENT	1708.	1762.	15062.	17826.	0.	1246.	2035.	39639.	79.28
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	171.	176.	1506.	1783.	0.	125.	44.	3804.	7.61
INTEREST DURING CONSTRUCTION (15.6 %)	266.	275.	2350.	2781.	0.	194.	317.	6184.	12.37
ROYALTIES (1.0 %)	10.	11.	91.	108.	0.	8.	3.	230.	0.46
LAND (6000. $/ACRE)	2.	2.	3.	2.	0.	1.	157.	166.	0.33
WORKING CAPITAL	67.	69.	591.	700.	0.	49.	91.	1567.	3.13
TOTAL CAPITAL INVESTMENT	2225.	2295.	19603.	23199.	0.	1622.	2646.	51590.	103.18

(Continued)

TABLE 8. (Continued)

LIME SPRAY DRYER -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

DISPLAY SHEET FOR YEAR= 1
ANNUAL OPERATION KW-HR/KW = 5500

	ANNUAL QUANTITY	UNIT COST,$	TOTAL ANNUAL COST,$
DIRECT COSTS			
RAW MATERIAL			
LIME	10.4 K TONS	90.00/TON	939000
SUBTOTAL RAW MATERIAL			939000
CONVERSION COSTS			
OPERATING LABOR AND SUPERVISION	29950.0 MAN-HR	19.00/MAN-HR	569000
LANDFILL LABOR AND SUPERVISION	24960.0 MAN-HR	24.00/MAN-HR	599000
UTILITIES			
PROCESS WATER	141150.0 K GAL	0.16/K GAL	22600
ELECTRICITY	22385800.0 KWH	0.055/KWH	1231200
DIESEL FUEL	35620.0 GAL	1.60/GAL	57000
MAINTENANCE			
LABOR AND MATERIAL			1499400
ANALYSES	4580.0 HR	26.00/HR	119200
SUBTOTAL CONVERSION COSTS			4097400
SUBTOTAL DIRECT COSTS			5036400
INDIRECT COSTS			
OVERHEADS			
PLANT AND ADMINISTRATIVE (60.0% OF CONVERSION COSTS LESS UTILITIES)			1672000
FIRST YEAR OPERATING AND MAINTENANCE COSTS			6708400
LEVELIZED CAPITAL CHARGES(15.60% OF TOTAL CAPITAL INVESTMENT)			8048000
FIRST YEAR ANNUAL REVENUE REQUIREMENTS			14756400
EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			5.37
LEVELIZED OPERATING AND MAINTENANCE (1.886 TIMES FIRST YEAR OPER. & MAIN.)			12652000
LEVELIZED CAPITAL CHARGES(15.60% OF TOTAL CAPITAL INVESTMENT)			8048000
LEVELIZED ANNUAL REVENUE REQUIREMENTS			20700000
EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)			7.53

HEAT RATE 10500. BTU/KWH - HEAT VALUE OF COAL 8200 BTU/LB - COAL RATE 1760700 TONS/YR

The baghouse air-to-cloth ratio, variable AC (in $aft^3/min/ft^2$ of cloth area), is specified by the user. This value is input as the net air-to-cloth ratio and is based on the baghouse inlet flue gas conditions. An example using a lower air-to-cloth ratio of 1.5 is provided in Table 9 and can be compared with the example output in Appendix D. The baghouse is further designed by the user through inputs such as the total number of baghouses (NTBAGN), the total number of baghouse compartments per baghouse (BAGCOM), and the bag cost (BGCOST) in $\$/ft^2$ of cloth. (BGCOST is specified in $\$/ft^2$ so differences in bag size or material of construction can be input by the user simply by entering a different unit cost value for the bag.) Teflon-coated fiberglass bags are used in the examples illustrated in Table 9 and Appendix D.

Operating Profile Option

One of the most important variables affecting the economics of a power plant and an associated FGD system is its anticipated operating profile (number of years of operation and the hours of operation per year) over the remaining life of the unit. The effects of the year-by-year profile on capital investment and annual revenue requirements are determined by the economic premises and the operating and maintenance cost levelizing factor FACLEV (line 17 of input). The model includes four options for specifying this profile and is controlled by the input variable IOPSCH on line 14 in the input data set.

Line No.	Input data
14	1985 1987 3 30 0 0 70 IOPSCH IYROP ONCAP

If IOPSCH = 1, the model uses the operating schedule shown in Figure 2 which is based on a profile developed by TVA many years ago for economic evaluations, but is no longer widely used. If IOPSCH = 2, a levelized operating profile of 5,500 hr/yr is used (see the example case in Appendix D). A 30-year operating life is used for both IOPSCH = 1 or IOPSCH = 2 and cannot be modified. The normal operating profile is IOPSCH = 2.

The remaining two operating profiles are more flexible but involve the use of two additional input values, IYROP and ONCAP. The variable IYROP (also on line 14) specifies the remaining operating life of the unit in years which cannot exceed 50. The variables ONCAP (also on line 14) specifies the capacity factor for the unit. When IOPSCH = 3, the operating profile is constructed using the user-supplied capacity factor (ONCAP) and the operating life (IYROP) for the plant. The operating capacity factor specified by the user (lifetime hours) is ignored by the model except when IOPSCH = 3. Example output using a user-supplied capacity factor is shown in Table 10.

When IOPSCH = 4, an operating profile is input by the user in the form of hours per year for each year in the remaining life of the unit, beginning on line 20. The total number of hour-per-year entries (i.e., years of remaining

TABLE 9. EXAMPLE RESULTS ILLUSTRATING BAGHOUSE AIR-TO-CLOTH RATIO OPTION

DFGD SYSTEM EQUIPMENT LIST ITEM (QUANTITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 3 -- GAS HANDLING		
1. FAN (4): INDUCED DRAFT, 442333. ACFM, 13.8-IN. STATIC HEAD, 1372.-HP	1371901.	63825.
	1371901.	63825.
AREA 4 -- SO2 ABSORPTION		
1. TANK, HEAD (4): 2.1-FT DIA. X 5.3-FT HIGH, 162. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	2911.	2426.
2. SPRAY DRYER (4): 48.7-FT DIA. X 34.6-FT STRAIGHT SIDE HEIGHT, 520768. ACFM, 60 DEGREE CONICAL HOPPER, INCLUDES 700-HP ATOMIZER, (3 OPERATING, 1 SPARE)	6975179.	935901.
	6978089.	938327.
AREA 5 -- PARTICULATE REMOVAL		
1. BAGHOUSE (2): REVERSE AIR, 884665. ACFM, 1.50 OPERATING AIR-TO-CLOTH RATIO, 16. TOTAL COMPARTMENTS PER BAGHOUSE, 8. OPERATING COMPARTMENTS PER BAGHOUSE	9430557.	14836945.
2. CONVEYOR, BAGHOUSE PARTICULATE REMOVAL (4): BELT, 18-IN. WIDE X 272.-FT LONG, 3.5-HP, 11.4 TONS/HR (TWO PER BAGHOUSE)	192421.	26787.
3. CONVEYOR, BAGHOUSE PARTICULATE COLLECTION (1): BELT, 18-IN. WIDE X 91.-FT LONG, 3.5-HP, 45.7 TONS/HR	38093.	5182.
4. ELEVATOR, BAGHOUSE PARTICULATE COLLECTION (1): CONTINUOUS BUCKET, 3.5-HP , 25.-FT LIFT, 45.7 TONS/HR	19800.	1135.
5. BIN, BAGHOUSE PARTICULATE SURGE (2): 7.-FT DIA. X 11.-FT STRAIGHT SIDE HEIGHT, COVERED, 45-DEGREE CONE HOPPER, CARBON STEEL, INCLUDES HOPPER HEATER	6149.	3793.
6. CONVEYOR, BAGHOUSE PARTICULATE DISPOSAL (1): PNUEMATIC, PRESSURE, 250.0-HP	234281.	80846.
7. SILO, PARTICULATE DISPOSAL (1): 20.-FT DIA. X 30.-FT STRAIGHT SIDE HEIGHT, 9795. FT3, CONCRETE CONSTRUCTION	33678.	60099.
8. HOPPER, PARTICULATE DISPOSAL SILO (1): 45-DEGREE CONE, CARBON STEEL	8217.	3496.
9. DUST COLLECTOR, PARTICULATE DISPOSAL SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	9970485.	15021240.

(Continued)

TABLE 9. (Continued)

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	430.	385.	1372.	6979.	9970.	406.	68.	19611.	39.22
LABOR	222.	119.	64.	939.	15021.	132.	78.	16574.	33.15
PIPING									
MATERIAL	0.	49.	0.	265.	0.	0.	0.	314.	0.63
LABOR	0.	66.	0.	94.	0.	0.	0.	160.	0.32
DUCTWORK									
MATERIAL	0.	0.	4267.	0.	0.	0.	0.	4267.	8.53
LABOR	0.	0.	3052.	0.	0.	0.	0.	3052.	6.10
FOUNDATIONS									
MATERIAL	15.	23.	51.	235.	122.	10.	5.	463.	0.93
LABOR	27.	44.	92.	422.	222.	19.	9.	835.	1.67
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	292.	4.	3.	373.	0.75
LABOR	17.	15.	0.	0.	390.	3.	1.	425.	0.85
ELECTRICAL									
MATERIAL	92.	108.	164.	85.	95.	79.	64.	688.	1.38
LABOR	51.	51.	626.	70.	39.	23.	15.	876.	1.75
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	157.	30.	9.	642.	1.28
LABOR	2.	15.	4.	40.	70.	9.	1.	141.	0.28
BUILDINGS									
MATERIAL	34.	0.	0.	541.	0.	0.	0.	575.	1.15
LABOR	14.	0.	0.	221.	0.	0.	0.	235.	0.47
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	49.	53.	442.	628.	798.	40.	11.	2020.	4.04
TOTAL PROCESS CAPITAL	1033.	1066.	10175.	10781.	27176.	756.	264.	51251.	102.50
SERVICES AND MISCELLANEOUS (6.0 %)	62.	64.	611.	647.	1631.	45.	16.	3075.	6.15
TOTAL DIRECT PROCESS INVESTMENT	1095.	1130.	10786.	11428.	28807.	801.	280.	54326.	108.65
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2006.	2006.	4.01
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	65.	65.	0.13
TOTAL DIRECT INVESTMENT	1095.	1130.	10786.	11428.	28807.	801.	2981.	57027.	114.05
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	77.	79.	755.	800.	2016.	56.	20.	3803.	7.61
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	22.	23.	216.	229.	576.	16.	6.	1087.	2.17
CONSTRUCTION EXPENSES (16.0 %)	175.	181.	1726.	1829.	4609.	128.	45.	8692.	17.38
CONTRACTOR FEES (5.0 %)	55.	56.	539.	571.	1440.	40.	14.	2716.	5.43
CONTINGENCY (20.0 %)	285.	294.	2804.	2971.	7490.	208.	73.	14125.	28.25
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	929.	929.	1.86
TOTAL FIXED INVESTMENT	1708.	1762.	16826.	17828.	44938.	1249.	4067.	88379.	176.76
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	171.	176.	1683.	1783.	4494.	125.	44.	8475.	16.95
INTEREST DURING CONSTRUCTION (15.6 %)	266.	275.	2625.	2781.	7010.	195.	634.	13787.	27.57
ROYALTIES (1.0 %)	10.	11.	102.	108.	272.	8.	3.	513.	1.03
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	57.	59.	563.	597.	1504.	42.	156.	2977.	5.95
TOTAL CAPITAL INVESTMENT	2215.	2285.	21801.	23098.	58221.	1619.	5331.	114570.	229.14

(Continued)

TABLE 9. (Continued)

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

  PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                      DISPLAY SHEET FOR YEAR=     1
                                     ANNUAL OPERATION KW-HR/KW =  5500
                                                                                   TOTAL
                                                                                   ANNUAL
                                               ANNUAL QUANTITY        UNIT COST,$   COST,$
                                               ---------------        -----------   ------
          DIRECT COSTS
          ------------
            RAW MATERIAL
            ------------
              LIME                               10.4 K TONS          90.00/TON        939000
                                                                                   ----------
                 SUBTOTAL RAW MATERIAL                                                 939000

            CONVERSION COSTS
            ----------------
              OPERATING LABOR AND
                SUPERVISION                    31410.0 MAN-HR         19.00/MAN-HR     596700
              LANDFILL LABOR AND
                SUPERVISION                    24960.0 MAN-HR         24.00/MAN-HR     599000
              UTILITIES
                PROCESS WATER                 142670.0 K GAL           0.16/K GAL       22800
                ELECTRICITY                 34939710.0 KWH             0.055/KWH      1921700
                DIESEL FUEL                    48280.0 GAL             1.60/GAL         77300
              MAINTENANCE
                LABOR AND MATERIAL                                                    3340400
              ANALYSES                          5330.0 HR             26.00/HR         138600
                                                                                   ----------
                 SUBTOTAL CONVERSION COSTS                                            6696500

                 SUBTOTAL DIRECT COSTS                                                7635500

          INDIRECT COSTS
          --------------
            OVERHEADS
              PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)     2804800
                                                                                   ----------
            FIRST YEAR OPERATING AND MAINTENANCE COSTS                               10440300
            LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)           17871900
                                                                                   ----------
               FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                28312200

               EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)   10.30
--------------------------------------------------------------------------------------------------------------
            LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)  19690400
            LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)           17871900
                                                                                   ----------
               LEVELIZED ANNUAL REVENUE REQUIREMENTS                                 37562300

               EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)     13.66
--------------------------------------------------------------------------------------------------------------
            HEAT RATE  10500. BTU/KWH     -    HEAT VALUE OF COAL      8200 BTU/LB     -    COAL RATE   1760700 TONS/YR
```

TYPING GUIDE SHEET

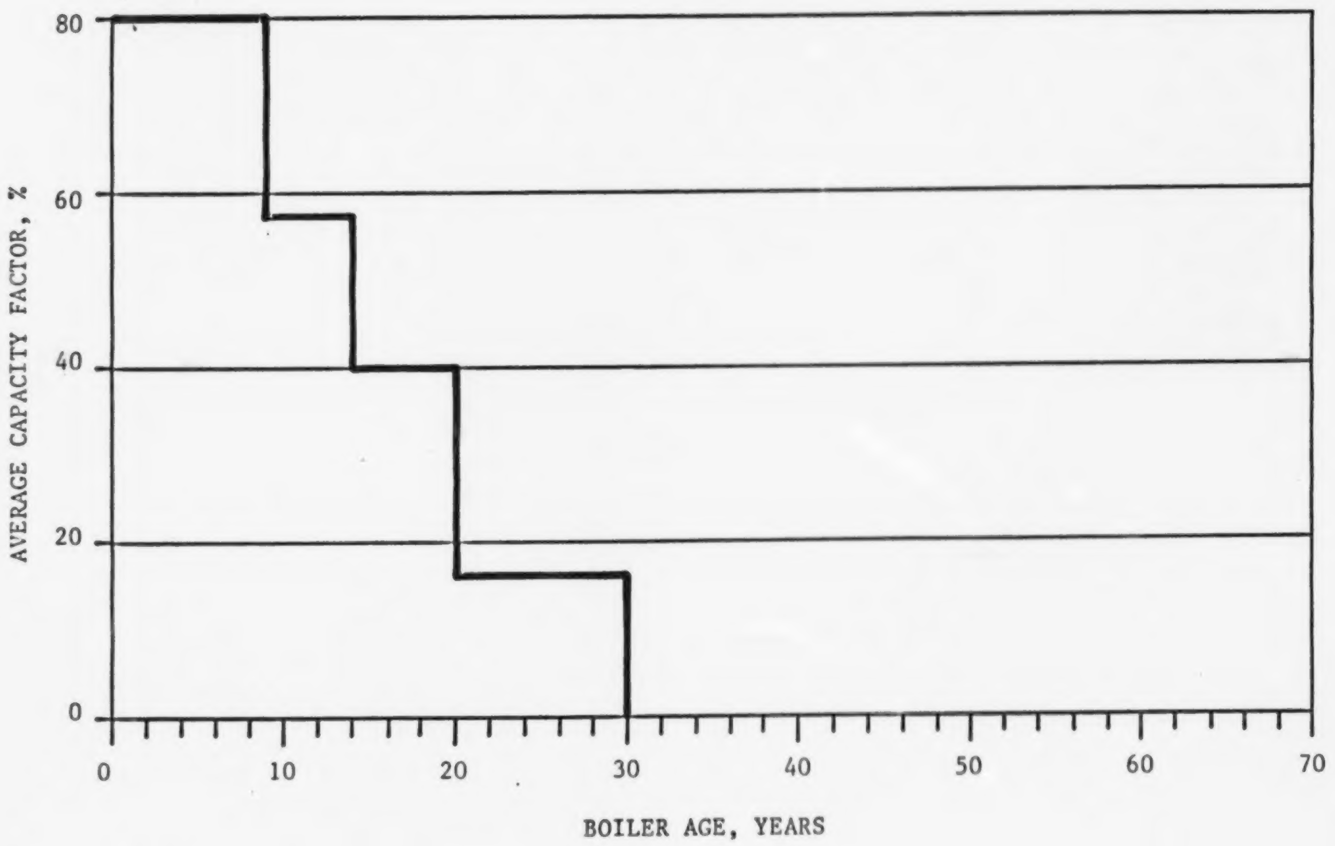

Figure 2. Operating profile assumed for IOPSCH = 1 based on old TVA premises.

TABLE 10. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING A USER-SPECIFIED PLANT LIFETIME PROFILE AND OPERATING CAPACITY FACTOR

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP
  PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                   DISPLAY SHEET FOR YEAR=    1
                                  ANNUAL OPERATION KW-HR/KW =  6131
                                                                                    TOTAL
                                                                                    ANNUAL
                                             ANNUAL QUANTITY     UNIT COST,$        COST,$
        DIRECT COSTS                         ---------------     -----------        ------
        ------------
          RAW MATERIAL
          ------------
            LIME                               11.6 K TONS       90.00/TON         1046800
                                                                                ----------
              SUBTOTAL RAW MATERIAL                                              1046800
          CONVERSION COSTS
          ----------------
            OPERATING LABOR AND
              SUPERVISION                    33120.0 MAN-HR      19.00/MAN-HR       629300
            LANDFILL LABOR AND
              SUPERVISION                    24960.0 MAN-HR      24.00/MAN-HR       599000
            UTILITIES
              PROCESS WATER                 159040.0 K GAL        0.16/K GAL         25400
              ELECTRICITY                 38926580.0 KWH          0.055/KWH        2141000
              DIESEL FUEL                    48300.0 GAL          1.60/GAL           77300
            MAINTENANCE
              LABOR AND MATERIAL                                                   2981700
            ANALYSES                          5610.0 HR          26.00/HR           145800
                                                                                ----------
              SUBTOTAL CONVERSION COSTS                                          6599500

              SUBTOTAL DIRECT COSTS                                              7646300
        INDIRECT COSTS
        --------------
          OVERHEADS
            PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)   2613800
                                                                                ----------
          FIRST YEAR OPERATING AND MAINTENANCE COSTS                              10259800
          LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)          16023300
                                                                                ----------
              FIRST YEAR ANNUAL REVENUE REQUIREMENTS                              26283100

              EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)     8.57
-------------------------------------------------------------------------------------------------------
        HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1962700 TONS/YR
```

(Continued)

TABLE 10. (Continued)

LIME SPRAY DRYER -- BASIS; 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW -- 11 USER CAP FACTOR

TOTAL CAPITAL INVESTMENT: $ 102720000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY PARTICULATES	NET REVENUE $/TON DRY PARTICULATES	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING BYPRODUCT SALES COST, $/YEAR	TOTAL NET BYPRODUCT SALES COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	6131	32187800	1962700	5200	125100	0.00	26284500	0	26284500	26284500
2	6131	32187800	1962700	5200	125100	0.00	26900100	0	26900100	53184600
3	6131	32187800	1962700	5200	125100	0.00	27552500	0	27552500	80737100
4	6131	32187800	1962700	5200	125100	0.00	28244400	0	28244400	108981500
5	6131	32187800	1962700	5200	125100	0.00	28977500	0	28977500	137959000
6	6131	32187800	1962700	5200	125100	0.00	29754800	0	29754800	167713800
7	6131	32187800	1962700	5200	125100	0.00	30578300	0	30578300	198292100
8	6131	32187800	1962700	5200	125100	0.00	31451700	0	31451700	229743800
9	6131	32187800	1962700	5200	125100	0.00	32377600	0	32377600	262121400
10	6131	32187800	1962700	5200	125100	0.00	33358600	0	33358600	295480000
11	6131	32187800	1962700	5200	125100	0.00	34398700	0	34398700	329878700
12	6131	32187800	1962700	5200	125100	0.00	35501200	0	35501200	365379900
13	6131	32187800	1962700	5200	125100	0.00	36669700	0	36669700	402049600
14	6131	32187800	1962700	5200	125100	0.00	37908500	0	37908500	439958100
15	6131	32187800	1962700	5200	125100	0.00	39221500	0	39221500	479179600
16	6131	32187800	1962700	5200	125100	0.00	40613100	0	40613100	519792700
17	6131	32187800	1962700	5200	125100	0.00	42088600	0	42088600	561881300
18	6131	32187800	1962700	5200	125100	0.00	43652500	0	43652500	605533800
19	6131	32187800	1962700	5200	125100	0.00	45310300	0	45310300	650844100
20	6131	32187800	1962700	5200	125100	0.00	47067500	0	47067500	697911600
21	6131	32187800	1962700	5200	125100	0.00	48930000	0	48930000	746841600
22	6131	32187800	1962700	5200	125100	0.00	50904300	0	50904300	797745900
23	6131	32187800	1962700	5200	125100	0.00	52997000	0	52997000	850742900
24	6131	32187800	1962700	5200	125100	0.00	55215400	0	55215400	905958300
25	6131	32187800	1962700	5200	125100	0.00	57566800	0	57566800	963525100
26	6131	32187800	1962700	5200	125100	0.00	60059500	0	60059500	1023584600
27	6131	32187800	1962700	5200	125100	0.00	62701700	0	62701700	1086286300
28	6131	32187800	1962700	5200	125100	0.00	65502200	0	65502200	1151788500
29	6131	32187800	1962700	5200	125100	0.00	68470900	0	68470900	1220259400
30	6131	32187800	1962700	5200	125100	0.00	71617600	0	71617600	1291877000
TOT	183930	965634000	58881000	156000	3753000		1291877000	0	1291877000	
LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT										
DOLLARS PER TON OF COAL BURNED							21.94	0.00	21.94	
MILLS PER KILOWATT-HOUR							14.05	0.00	14.05	
DOLLARS PER TON OS SULFUR REMOVED							8281.26	0.00	8281.26	
CENTS PER MILLION BTU HEAT INPUT							133.79	0.00	133.79	
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS							323134700	0	323134700	
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							17.46	0.00	17.46	
MILLS PER KILOWATT-HOUR							11.18	0.00	11.18	
CENTS PER MILLION BTU HEAT INPUT							106.49	0.00	106.49	
DOLLARS PER TON OF SULFUR REMOVED							6594.59	0.00	6594.59	

UNIT COSTS INFLATED AT 6.00% PER YEAR

life) must be equal to the value for IYROP in the data set. The hours per year for the first 10 years of the operating profile are listed on line 20. The hours per year for the next 10 years of the operating profile are listed on line 21. Less than 10 entries per line are allowed on the last line only. The user should leave a blank space between each entry (hours per year) on these input lines. Also, no commas can be used. Example output resulting from a user-supplied operating profile (IOPSCH = 4) is shown in Table 11. The example case printout in Appendix D shows the results of specifying a levelized operating profile of 5,500 hr/yr (IOPSCH = 2).

Levelized Capital Charge and Levelizing Factors

The effects of changes in the assumed inflation rate and interest rate can be simulated by either inputting or having the model calculate levelized capital charge and levelizing factors using the variable found on lines 14, 15, and 17 of the data set.

```
Line No.     ______________Input data__________________

   14        1985  1987  3  30       0       0   70
                            ↓        ↓       ↓
                          IYROP    ICLEV   IDCAL

   15        7  2  16  5  20  10  14.7  10  6
                                  ↙      ↓
                              CONINT  XINT

   17        6  60    0.0     15.6    1.17  1  4  3.5  6  1
              ↘        ↓        ↓
             XINFLA  FACLEV  UNDCAP
```

The control variable for indicating whether the levelized capital charge and the levelizing factors are being input or calculated is ICLEV. If ICLEV is set at zero, the values for the levelized capital charge factor (UNDCAP) and the levelizing factor (FACLEV) in the data set are processed as input. When ICLEV is set at one, the levelized capital charge factor (UNDCAP) and the levelizing factor (FACLEV) are calculated using the values in the data set for the inflation rate (variable XINFLA), the cost of capital (variable XINT), and the remaining life of the plant (variable IYROP). These internally calculated values for UNDCAP and FACLEV are then used in the economic projections.

Interest During Construction

The effect of changes in the assumed construction schedule on the interest during construction cost can be simulated by inputting either an interest during construction cost factor or a construction schedule and having the model calculate the cost for interest during construction cost factor using the variables found in lines 13, 14 and 15 of the data set.

TABLE 11. EXAMPLE LIFETIME REVENUE REQUIREMENTS USING A USER-SPECIFIED OPERATING PROFILE

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                  DISPLAY SHEET FOR YEAR=     1
                               ANNUAL OPERATION KW-HR/KW =  6000
                                                                                   TOTAL
                                                                                  ANNUAL
                                              ANNUAL QUANTITY       UNIT COST,$   COST,$
         DIRECT COSTS                         ---------------       -----------   ------
         ------------
           RAW MATERIAL
           ------------
             LIME                                 11.4 K TONS        90.00/TON           1024400
                                                                                      ----------
               SUBTOTAL RAW MATERIAL                                                     1024400

           CONVERSION COSTS
           ----------------
             OPERATING LABOR AND
               SUPERVISION                      32770.0 MAN-HR       19.00/MAN-HR         622600
             LANDFILL LABOR AND
               SUPERVISION                      24960.0 MAN-HR       24.00/MAN-HR         599000
             UTILITIES
               PROCESS WATER                   155640.0 K GAL         0.16/K GAL           24900
               ELECTRICITY                   38090740.0 KWH           0.055/KWH          2095000
               DIESEL FUEL                      48250.0 GAL           1.60/GAL             77200
             MAINTENANCE
               LABOR AND MATERIAL                                                        2970400
             ANALYSES                            5550.0 HR           26.00/HR             144300
                                                                                      ----------
               SUBTOTAL CONVERSION COSTS                                                 6533400

               SUBTOTAL DIRECT COSTS                                                     7557800

         INDIRECT COSTS
         --------------
           OVERHEADS
             PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)        2601800
                                                                                      ----------
           FIRST YEAR OPERATING AND MAINTENANCE COSTS                                   10159600
           LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)               15912400
                                                                                      ----------
               FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                   26072000

               EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)    8.69
----------------------------------------------------------------------------------------------------------------
          HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1920700 TONS/YR
```

(Continued)

TABLE 11. (Continued)

```
     LIME SPRAY DRYER -- BASIS:  500 MW SCRUBBING    UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                        TOTAL CAPITAL INVESTMENT:  $  102003000

                                                                                   ADJUSTED GROSS
                                             SULFUR      BYPRODUCT                 ANNUAL REVENUE
                                             REMOVED       RATE,                   REQUIREMENT   TOTAL      NET ANNUAL   CUMULATIVE
YEARS ANNUAL  POWER UNIT    POWER UNIT         BY       EQUIVALENT    NET REVENUE   EXCLUDING     NET       INCREASE   NET INCREASE
AFTER OPERA-     HEAT          FUEL         POLLUTION    TONS/YEAR      $/TON       BYPRODUCT  BYPRODUCT    IN TOTAL     IN TOTAL
POWER TION,  REQUIREMENT, CONSUMPTION,      CONTROL                                   SALES      SALES      REVENUE      REVENUE
UNIT KW-HR   MILLION BTU   TONS COAL        PROCESS,       DRY          DRY           COST,      COST,    REQUIREMENT,REQUIREME NT,
START  /KW      /YEAR        /YEAR        TONS/YEAR   PARTICULATES  PARTICULATES    $/YEAR     $/YEAR         $            $
-------------------------------------------------------------------------------------------------------------------------------------
  1    6000   31500000      1920700         5100        122400         0.00       26072000         0     26072000     26072000
  2    6000   31500000      1920700         5100        122400         0.00       26681800         0     26681800     52753800
  3    6000   31500000      1920700         5100        122400         0.00       27328000         0     27328000     80081800
  4    6000   31500000      1920700         5100        122400         0.00       28013000         0     28013000    108094800
  5    6000   31500000      1920700         5100        122400         0.00       28739000         0     28739000    136833800
  6    6500   34125000      2080800         5500        132600         0.00       30313300         0     30313300    167147100
  7    6500   34125000      2080800         5500        132600         0.00       31177100         0     31177100    198324200
  8    6500   34125000      2080800         5500        132600         0.00       32093400         0     32093400    230417600
  9    6500   34125000      2080800         5500        132600         0.00       33064000         0     33064000    263481600
 10    6500   34125000      2080800         5500        132600         0.00       34093200         0     34093200    297574800
-------------------------------------------------------------------------------------------------------------------------------------
 11    5000   26250000      1600600         4200        102000         0.00       31889700         0     31889700    329464500
 12    5000   26250000      1600600         4200        102000         0.00       32848300         0     32848300    362312800
 13    5000   26250000      1600600         4200        102000         0.00       33864400         0     33864400    396177200
 14    5000   26250000      1600600         4200        102000         0.00       34941400         0     34941400    431118600
 15    5000   26250000      1600600         4200        102000         0.00       36083300         0     36083300    467201900
 16    5500   28875000      1760700         4600        112200         0.00       38792700         0     38792700    505994600
 17    5500   28875000      1760700         4600        112200         0.00       40165500         0     40165500    546160100
 18    5500   28875000      1760700         4600        112200         0.00       41620800         0     41620800    587780900
 19    5500   28875000      1760700         4600        112200         0.00       43163200         0     43163200    630944100
 20    5500   28875000      1760700         4600        112200         0.00       44798300         0     44798300    675742400
-------------------------------------------------------------------------------------------------------------------------------------
 21    4000   21000000      1280500         3400         81600         0.00       40363600         0     40363600    716106000
 22    4000   21000000      1280500         3400         81600         0.00       41830500         0     41830500    757936500
 23    4000   21000000      1280500         3400         81600         0.00       43385600         0     43385600    801322100
 24    4000   21000000      1280500         3400         81600         0.00       45034000         0     45034000    846356100
 25    4500   23625000      1440500         3800         91800         0.00       49443100         0     49443100    895799200
 26    1000    5250000       320100          800         20400         0.00       28768300         0     28768300    924567500
-------------------------------------------------------------------------------------------------------------------------------------

TOT  136500  716625000     43696600       115200       2784600                   924567500         0    924567500
   LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT
                          DOLLARS PER TON OF COAL BURNED                            21.16      0.00        21.16
                          MILLS PER KILOWATT-HOUR                                   13.55      0.00        13.55
                          CENTS PER MILLION BTU HEAT INPUT                         129.02      0.00       129.02
                          DOLLARS PER TON OF SULFUR REMOVED                       8025.76      0.00      8025.76
REVENUE REQUIREMENT DISCOUNTED AT  10.0% TO INITIAL YEAR, DOLLARS               292382200         0    292382200
   LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT
                          DOLLARS PER TON OF COAL BURNED                            17.32      0.00        17.32
                          MILLS PER KILOWATT-HOUR                                   11.09      0.00        11.09
                          CENTS PER MILLION BTU HEAT INPUT                         105.62      0.00       105.62
                          DOLLARS PER TON OF SULFUR REMOVED                       6555.65      0.00      6555.65
UNIT COSTS INFLATED AT   6.00% PER YEAR
```

```
Line No.                       Input data

  13       90  19  24  52  16  0.055  1.60  26  3  .25  .5  .25
                                                |  \___________/
                                                ↓
                                               II  TPI(K),K=1,II

  14       1985  1987  3  30      0       0   70
                          |       |       |
                          ↓       ↓       ↓
                        IYROP   ICLEV   IDCAL

  15       7  2  16  5  20  10  14.7    10   6
                                  |      |
                                  ↓      ↓
                               CONINT  XINT
```

The control variable for indicating whether the interest during construction cost factor will be based on an input value or calculated is the input variable IDCAL. If IDCAL is set at zero, the value for the interest during construction cost factor (CONINT) in the data set is processed as input. When IDCAL is set at one, a construction schedule of up to 10 years may be input using the variables II and TPI(K) where II is the number of years for construction and TPI(K) contains the percentage of the total capital borrowed in each year K. When the interest during construction cost factor is being calculated, the cost of capital (input as variable XINT) is used in the calculation. When IDCAL is set to one, the resulting computer calculated value is used in the economic projections.

Separate Waste Disposal Site Construction Indirect Investment Factors Option

The waste disposal indirect investment option allows the indirect capital investment for the waste disposal site construction to be calculated separately from the process indirect investment. The waste disposal site construction is usually less complicated than the FGD process construction and its indirect investment factors are usually lower. These inputs are located on line 16 of the data set.

```
Line No.                     Input data

  16        2      1      8       5      20      0     3   1.0
            |      |      |       |      |       |
            ↓      ↓      ↓       ↓      ↓       ↓
         SENGIN  SARCH  SFLDEX  SFEES  SCONT  SSTART
```

Variables SENGIN (engineering design and supervision), SARCH (architectural and engineering contractor), SFLDEX (field expenses), SFEES (contractor fees), SCONT (contingencies), and SSTART (allowance for startup and modifications) are used to determine the waste disposal site indirect investment. All but SCONT and SSTART are calculated as a percentage of waste disposal site direct investments. In the current economic premises, the contingency (SCONT) is calculated as percentage of the sum of the waste disposal site direct investments plus each of the four preceding waste disposal site indirect investments. The allowance for startup and modifications (SSTART) is calculated as a percentage of the total fixed investment (summation of all direct investments and the preceding indirect investments including contingency for waste disposal site construction). An example of output showing the use of separate indirect investment factors for landfill construction is shown in the example printout in Appendix D.

Landfill Capacity Option

The landfill capacity option SDCAP provides the user the capability to design the landfill site based on average sulfur content while simultaneously designing the raw material preparation, the spray dryer, and the particulate collection areas based on maximum sulfur content of coal (high-sulfur content fluctuation). For example, on a long-term basis, the coal being used may be expected to average 2.0% sulfur. However, at times the sulfur content may be as high as 3.0%. The raw material preparation area, the spray drying area, and the particulate collection area should be sized for the maximum coal sulfur content that is expected to be encountered. In this case, a value of 3.0% must be considered for design of the raw material area, the spray dryer area, and the particulate collection area, but the model also calculates the waste production rate based on the input sulfur content and sizes the disposal site based on that amount. Using the SDCAP option on line 16 of the data set allows the waste disposal site size to be modified to account for the difference between average and maximum sulfur content (ordinarily SDCAP will be in the range of 50-100).

Line No.	Input data
16	2 1 8 5 20 0 3 67 ↓ SDCAP

In the preceding example, by specifying SDCAP equal to 67, the waste disposal site would be sized based on a 2.0% sulfur coal; whereas, the other facilities would be designed for fluctuations in coal sulfur content of up to 3.0%.

If the user wishes to specify an oversized waste disposal site to cover contingencies, or to specify an undersized site for applications in which the initial site is not designed for the full life of the plant, an appropriate SDCAP factor, i.e., greater than or less than 100, can be specified.

Another use of this option is to prorate the FGD waste disposal and the fly ash normally disposed of by the facility without FGD control. This allows the model to project the design and cost of the landfill based only on the FGD waste.

Lifetime Economic Levelizing Option

Line No.	Input data
17	6 60 0.0 15.6 1.17 1 4 3.5 6 1 ↓ FACLEV

If levelized operating and maintenance costs under the current premises are used, a levelizing factor FACLEV that corresponds to the operating profile should be used. The factor FACLEV is applied to first-year operating and maintenance costs to develop levelized operating and maintenance costs for the total life of the plant. If the levelizing factor is set to zero, then a lifetime revenue sheet is printed showing annual revenue requirements for each year of plant operation. Example output showing the results of specifying a zero levelizing factor is shown in the example revenue requirements in Table 12.

Sales Tax and Freight Option

The sales tax and freight option ITAXFR allows the user to input the sales tax and freight rates to be applied as a percentage of material costs. The sales tax rate is specified with the variable TXRAT and the freight rate is specified with the variable FRRAT, both of which are located on line 17 of the input data set.

Line No.	Input data
17	6 60 1.886 15.6 1.17 0 0 0 6 1 ITAXFR TXRAT FRRAT

When ITAXFR = 1, the specified rates are applied to material costs and included in the capital investment summary printout; when ITAXFR is zero, sales tax and freight are excluded. Example output showing the results of specifying tax and freight is shown on the capital investment summary sheet in the example printout in Appendix D. An example investment summary sheet showing sales tax and freight excluded is shown in Table 13.

Landfill Disposal Option

The design of the landfill site used in the model is described in the premises section (Appendix B). The user may specify land cost ACRE$ in dollars and distance to the disposal site DISTLF on line 18 of the input data set while customizing the design of the landfill disposal site.

Line No.	Input data
18	6000 5280 1 12 6 ACRE$ DISTLF

Based on this design and volume of waste to be disposed of, the transportation and landfill construction requirements are determined. The bulk densities for the in-process waste and the compacted waste are defined in the premises as 70 and 85 lb/ft^3, respectively. These values are specified in the model and cannot be changed. Example output showing the results of specifying a base case landfill is shown in the printout in Appendix D. The type of liner is specified separately as discussed below.

TABLE 12. EXAMPLE REVENUE REQUIREMENTS USING THE ECONOMIC PREMISES WITH NO LEVELIZING FACTOR

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP
PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINOUS 500 MW

                                   DISPLAY SHEET FOR YEAR=     1
                                 ANNUAL OPERATION KW-HR/KW =  5500
                                                                                         TOTAL
                                                                                        ANNUAL
                                               ANNUAL QUANTITY       UNIT COST,$        COST,$
                                               ---------------       -----------        ------
           DIRECT COSTS
           ------------
             RAW MATERIAL
             ------------
               LIME                               10.4 K TONS        90.00/TON           939000
                                                                                     ----------
                 SUBTOTAL RAW MATERIAL                                                   939000

             CONVERSION COSTS
             ----------------
               OPERATING LABOR AND
                 SUPERVISION                   31410.0 MAN-HR        19.00/MAN-HR        596700
               LANDFILL LABOR AND
                 SUPERVISION                   24960.0 MAN-HR        24.00/MAN-HR        599000
               UTILITIES
                 PROCESS WATER                142670.0 K GAL          0.16/K GAL          22800
                 ELECTRICITY                34939710.0 KWH            0.055/KWH         1921700
                 DIESEL FUEL                   48280.0 GAL            1.60/GAL            77300
               MAINTENANCE
                 LABOR AND MATERIAL                                                     2977400
               ANALYSES                         5330.0 HP            26.00/HR            138600
                                                                                     ----------
                 SUBTOTAL CONVERSION COSTS                                              6333500

                 SUBTOTAL DIRECT COSTS                                                  7272500

           INDIRECT COSTS
           --------------
             OVERHEADS
               PLANT AND ADMINISTRATIVE ( 60.0% OF CONVERSION COSTS LESS UTILITIES)     2587000
                                                                                     ----------
             FIRST YEAR OPERATING AND MAINTENANCE COSTS                                 9659500
             LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)            15974000
                                                                                     ----------
                 FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                25833500

                 EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)   9.39
--------------------------------------------------------------------------------------------------------------
           HEAT RATE  10500. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -     COAL RATE   1760700 TONS/YR
```

(Continued)

TABLE 12. (Continued)

LIME SPRAY DRYER -- BASIS: 500 MW SCRUBBING UNIT - 500 MW GENERATING UNIT, 1987 STARTUP

PROJECTED LIFETIME REVENUE REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

TOTAL CAPITAL INVESTMENT: $ 102397000

YEARS AFTER POWER UNIT START	ANNUAL OPERATION, KW-HR /KW	POWER UNIT HEAT REQUIREMENT, MILLION BTU /YEAR	POWER UNIT FUEL CONSUMPTION, TONS COAL /YEAR	SULFUR REMOVED BY POLLUTION CONTROL PROCESS, TONS/YEAR	BYPRODUCT RATE, EQUIVALENT TONS/YEAR DRY PARTICULATES	NET REVENUE $/TON DRY PARTICULATES	ADJUSTED GROSS ANNUAL REVENUE REQUIREMENT EXCLUDING BYPRODUCT SALES COST, $/YEAR	TOTAL NET BYPRODUCT SALES COST, $/YEAR	NET ANNUAL INCREASE IN TOTAL REVENUE REQUIREMENT, $	CUMULATIVE NET INCREASE IN TOTAL REVENUE REQUIREMENT, $
1	5500	28875000	1760700	4600	112200	0.00	25833500	0	25833500	25833500
2	5500	28875000	1760700	4600	112200	0.00	26425100	0	26425100	52258600
3	5500	28875000	1760700	4600	112200	0.00	27052200	0	27052200	79310800
4	5500	28875000	1760700	4600	112200	0.00	27716900	0	27716900	107027700
5	5500	28875000	1760700	4600	112200	0.00	28421500	0	28421500	135449200
6	5500	28875000	1760700	4600	112200	0.00	29168300	0	29168300	164617500
7	5500	28875000	1760700	4600	112200	0.00	29960000	0	29960000	194577500
8	5500	28875000	1760700	4600	112200	0.00	30799200	0	30799200	225376700
9	5500	28875000	1760700	4600	112200	0.00	31688800	0	31688800	257065500
10	5500	28875000	1760700	4600	112200	0.00	32631600	0	32631600	289697100
11	5500	28875000	1760700	4600	112200	0.00	33630900	0	33630900	323328000
12	5500	28875000	1760700	4600	112200	0.00	34690200	0	34690200	358018200
13	5500	28875000	1760700	4600	112200	0.00	35813300	0	35813300	393831500
14	5500	28875000	1760700	4600	112200	0.00	37003800	0	37003800	430835300
15	5500	28875000	1760700	4600	112200	0.00	38265300	0	38265300	469100600
16	5500	28875000	1760700	4600	112200	0.00	39602700	0	39602700	508703300
17	5500	28875000	1760700	4600	112200	0.00	41020800	0	41020800	549724100
18	5500	28875000	1760700	4600	112200	0.00	42523600	0	42523600	592247700
19	5500	28875000	1760700	4600	112200	0.00	44116500	0	44116500	636364200
20	5500	28875000	1760700	4600	112200	0.00	45804900	0	45804900	682169100
21	5500	28875000	1760700	4600	112200	0.00	47594800	0	47594800	729763900
22	5500	28875000	1760700	4600	112200	0.00	49492200	0	49492200	779256100
23	5500	28875000	1760700	4600	112200	0.00	51503200	0	51503200	830759300
24	5500	28875000	1760700	4600	112200	0.00	53634900	0	53634900	884394200
25	5500	28875000	1760700	4600	112200	0.00	55894500	0	55894500	940288700
26	5500	28875000	1760700	4600	112200	0.00	58289900	0	58289900	998578600
27	5500	28875000	1760700	4600	112200	0.00	60828800	0	60828800	1059407400
28	5500	28875000	1760700	4600	112200	0.00	63519900	0	63519900	1122927300
29	5500	28875000	1760700	4600	112200	0.00	66372800	0	66372800	1189300100
30	5500	28875000	1760700	4600	112200	0.00	69396500	0	69396500	1258696600
TOT	165000	866250000	52821000	138000	3366000		1258696600	0	1258696600	
LIFETIME AVERAGE INCREASE IN UNIT REVENUE REQUIREMENT										
DOLLARS PER TON OF COAL BURNED							23.83	0.00	23.83	
MILLS PER KILOWATT-HOUR							15.26	0.00	15.26	
CENTS PER MILLION BTU HEAT INPUT							145.30	0.00	145.30	
DOLLARS PER TON OF SULFUR REMOVED							9120.99	0.00	9120.99	
REVENUE REQUIREMENT DISCOUNTED AT 10.0% TO INITIAL YEAR, DOLLARS							315941800	0	315941800	
LEVELIZED INCREASE IN UNIT REVENUE REQUIREMENT EQUIVALENT TO DISCOUNTED REQUIREMENT OVER LIFE OF POWER UNIT										
DOLLARS PER TON OF COAL BURNED							19.03	0.00	19.03	
MILLS PER KILOWATT-HOUR							12.19	0.00	12.19	
CENTS PER MILLION BTU HEAT INPUT							116.07	0.00	116.07	
DOLLARS PER TON OF SULFUR REMOVED							7296.58	0.00	7296.58	

TABLE 13. EXAMPLE INVESTMENT SUMMARY TABLE WITH SALES TAX AND FREIGHT EXCLUDED

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	430.	385.	1372.	6978.	7433.	406.	68.	17072.	34.14
LABOR	222.	119.	64.	938.	12242.	132.	78.	13794.	27.59
PIPING									
MATERIAL	0.	49.	0.	265.	0.	0.	0.	314.	0.63
LABOR	0.	66.	0.	94.	0.	0.	0.	160.	0.32
DUCTWORK									
MATERIAL	0.	0.	4267.	0.	0.	0.	0.	4267.	8.53
LABOR	0.	0.	3052.	0.	0.	0.	0.	3052.	6.10
FOUNDATIONS									
MATERIAL	15.	23.	51.	235.	107.	8.	5.	445.	0.89
LABOR	27.	44.	92.	422.	194.	19.	9.	807.	1.61
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	214.	4.	3.	295.	0.59
LABOR	17.	15.	0.	0.	318.	3.	1.	352.	0.70
ELECTRICAL									
MATERIAL	92.	108.	164.	85.	95.	79.	64.	688.	1.38
LABOR	51.	51.	626.	70.	39.	23.	15.	876.	1.75
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	157.	30.	9.	642.	1.28
LABOR	2.	15.	4.	40.	70.	9.	1.	141.	0.28
BUILDINGS									
MATERIAL	34.	0.	0.	541.	0.	0.	0.	575.	1.15
LABOR	14.	0.	0.	221.	0.	0.	0.	235.	0.47
TOTAL PROCESS CAPITAL	984.	1013.	9733.	10153.	20868.	714.	253.	43717.	87.43
SERVICES AND MISCELLANEOUS (6.0 %)	59.	61.	584.	609.	1252.	43.	15.	2623.	5.25
TOTAL DIRECT PROCESS INVESTMENT	1043.	1074.	10317.	10762.	22120.	757.	266.	46340.	92.68
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2006.	2006.	4.01
TOTAL DIRECT INVESTMENT	1043.	1074.	10317.	10762.	22120.	757.	2904.	48977.	97.95
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	73.	75.	722.	753.	1548.	53.	19.	3244.	6.49
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	21.	21.	206.	215.	442.	15.	5.	927.	1.85
CONSTRUCTION EXPENSES (16.0 %)	167.	172.	1651.	1722.	3539.	121.	43.	7414.	14.83
CONTRACTOR FEES (5.0 %)	52.	54.	516.	538.	1106.	38.	13.	2317.	4.63
CONTINGENCY (20.0 %)	271.	279.	2682.	2799.	5751.	197.	70.	12046.	24.10
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	912.	912.	1.82
TOTAL FIXED INVESTMENT	1627.	1675.	16095.	16788.	34507.	1181.	3967.	75840.	151.68
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	163.	168.	1609.	1679.	3451.	118.	42.	7229.	14.46
INTEREST DURING CONSTRUCTION (15.6 %)	254.	261.	2511.	2619.	5383.	184.	615.	11831.	23.66
ROYALTIES (1.0 %)	10.	10.	97.	102.	209.	7.	3.	437.	0.87
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	56.	58.	556.	580.	1192.	41.	157.	2639.	5.28
TOTAL CAPITAL INVESTMENT	2112.	2174.	20871.	21770.	44744.	1531.	5214.	98417.	196.83

Landfill Site Liner Option

The liner option allows a choice of an unlined, clay-lined, or synthetic-lined disposal site. The input variables ILINER, XLINA, and XLINB are located on line 18 of the data set.

```
Line No.     Input data

  18         6000 5280 2 3.50 1.25
                  ILINER XLINA XLINB
```

The liner requirements are usually determined by environmental requirements, reactivity of the wastes, and permeability of the site. For lime-based systems, a clay-lined site is usually sufficient. ILINER specifies the type of lining as illustrated below:

1 - Clay liner

2 - Synthetic liner

3 - No liner

For a clay liner (ILINER = 1), XLINA specifies the depth of clay in inches and XLINB specifies the clay lining installation cost (or the costs for reworking the clay topsoil into a lining) in $\$/yd^3$. For a synthetic liner (ILINER = 2), XLINA specifies the liner material cost in $\$/yd^2$ and XLINB specifies the installation cost in $\$/yd^2$. For no liner (ILINER = 3), XLINA and XLINB should be set to zero. Example output showing the results of specifying a synthetic liner is shown in Table 14.

Overtime Option

The overtime option IOTIME allows an overtime labor rate OTRATE to be applied to 7% of total capital investment labor as defined in the premises in Appendix B.

```
Line No.     Input data

  19             1 1.5 1.0 366.8 292.2 346
         IOTIME OTRATE
```

When IOTIME = 1, the specified overtime is applied to 7% of all applicable labor costs; when IOTIME = 0, no overtime labor adjustments are made. The added costs for overtime labor are not shown separately in the model output, but a message is printed in the listing of the model inputs to indicate that overtime labor is specified at the overtime labor rate of OTRATE. An example printout with overtime specified is shown in the base case printout in Appendix D.

TABLE 14. EXAMPLE RESULTS ILLUSTRATING LANDFILL DISPOSAL

WITH SYNTHETIC LINER

```
LANDFILL DESIGN
-------- ------

LANDFILL DIMENSIONS
-------- ----------


HEIGHT OF LANDFILL                  89.67 FT
HEIGHT OF LANDFILL CAP              69.67 FT
SLOPE OF LANDFILL CAP                5.   DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE  1425.   FT
LENGTH OF LANDFILL TRENCH         5849.   FT
LENGTH OF PERIMETER FENCE         7651.   FT

SURFACE AREA OF LANDFILL          2059.   THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN    2193.   THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE    327.   THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL    2033.   THOUSAND FT2
LAND AREA OF LANDFILL SITE        3084.   THOUSAND FT2
LAND AREA OF LANDFILL SITE          71.   ACRES

VOLUME OF EXCAVATION               181.   THOUSAND YD3
VOLUME OF RECLAIM STORAGE          177.   THOUSAND YD3
VOLUME OF SLUDGE TO BE            2934.   THOUSAND YD3
 DISPOSED OVER LIFE OF PLANT      1913.   ACRE FT

DENSITY OF DISCHARGE CAKE           70.00 LBS/FT3
DENSITY OF COMPACTED CAKE           85.00 LBS/FT3

DEPTH OF CATCHMENT POND             23.36 FT
LENGTH OF CATCHMENT POND           302.19 FT
VOLUME OF CATCHMENT POND            57.   THOUSAND YD3
```

(Continued)

TABLE 14. (Continued)

```
LANDFILL COSTS (THOUSANDS OF DOLLARS)
-------- ----- ---------- -- --------


LANDFILL EQUIPMENT                                            631.
TAX AND FREIGHT                                                46.

LANDFILL EQUIPMENT TOTAL                                      677.
------------------------------------------------------------------
                                        LABOR   MATERIAL   TOTAL
                                        -----   --------   -----

CLEARING LAND                            156.               156.
EXCAVATION                               357.               357.
DISCHARGE TRENCH                          19.                19.
LINING(SYNTHETIC)                        351.     1018.    1370.
DRAINAGE LANDFILL                          0.        0.       0.
SEEDING LANDFILL SITE                     58.       34.      93.
ROAD CONSTRUCTION                         71.       41.     112.
PERIMETER COSTS, FENCE                    52.       58.     111.
RECLAMATION EXPENSE                      166.               166.
RECLAMATION SYNTHETIC COVER              445.      903.    1348.
MONITOR WELLS                              6.        5.      11.
------------------------------------------------------------------
SUBTOTAL DIRECT                         2245.     2060.    4305.
TAX AND FREIGHT                                    155.     155.
------------------------------------------------------------------
TOTAL DIRECT LANDFILL,INVESTMENT        2245.     2215.    4460.
------------------------------------------------------------------
ENGINEERING DESIGN AND SUPERVISION ( 2.0 )                   89.
ARCHITECT AND ENGINEERING CONTRACTOR( 1.0 )                  45.
CONSTRUCTION EXPENSES ( 8.0 )                               357.
CONTRACTOR FEES ( 5.0 )                                     223.
CONTINGENCY (20.0 )                                        1170.
------------------------------------------------------------------

TOTAL FIXED INVESTMENT                                     7020.

LAND COST                                                   425.

REVENUE QUANTITIES
------- ----------


LANDFILL LABOR      24960.  MAN-HRS
DIESEL FUEL         48284.  GALLONS
ELECTRICITY         95294.  KWH
WATER                1905.  K-GALLONS
ANALYSIS               20.  MAN-HRS
```

(Continued)

TABLE 14. (Continued)

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	430.	385.	1372.	6978.	7433.	406.	68.	17072.	34.14
LABOR	222.	119.	64.	938.	12242.	132.	78.	13794.	27.59
PIPING									
MATERIAL	0.	49.	0.	265.	0.	0.	0.	314.	0.63
LABOR	0.	66.	0.	94.	0.	0.	0.	160.	0.32
DUCTWORK									
MATERIAL	0.	0.	4267.	0.	0.	0.	0.	4267.	8.53
LABOR	0.	0.	3052.	0.	0.	0.	0.	3052.	6.10
FOUNDATIONS									
MATERIAL	15.	23.	51.	235.	107.	8.	5.	445.	0.89
LABOR	27.	44.	92.	422.	194.	19.	9.	807.	1.61
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	214.	4.	3.	295.	0.59
LABOR	17.	15.	0.	0.	318.	3.	1.	352.	0.70
ELECTRICAL									
MATERIAL	92.	108.	164.	85.	95.	79.	64.	688.	1.38
LABOR	51.	51.	626.	70.	39.	23.	15.	876.	1.75
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	157.	30.	9.	642.	1.28
LABOR	2.	15.	4.	40.	70.	9.	1.	141.	0.28
BUILDINGS									
MATERIAL	34.	0.	0.	541.	0.	0.	0.	575.	1.15
LABOR	14.	0.	0.	221.	0.	0.	0.	235.	0.47
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	49.	53.	442.	627.	600.	40.	11.	1822.	3.64
TOTAL PROCESS CAPITAL	1033.	1066.	10175.	10780.	21468.	754.	264.	45540.	91.08
SERVICES AND MISCELLANEOUS (6.0 %)	62.	64.	611.	647.	1288.	45.	16.	2732.	5.46
TOTAL DIRECT PROCESS INVESTMENT	1095.	1130.	10786.	11427.	22756.	799.	280.	48272.	96.54
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	4305.	4305.	8.61
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	201.	201.	0.40
TOTAL DIRECT INVESTMENT	1095.	1130.	10786.	11427.	22756.	799.	5416.	53409.	106.82
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	77.	79.	755.	800.	1593.	56.	20.	3379.	6.76
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	22.	23.	216.	229.	455.	16.	6.	965.	1.93
CONSTRUCTION EXPENSES (15.0 %)	175.	181.	1726.	1828.	3641.	128.	45.	7724.	15.45
CONTRACTOR FEES (5.0 %)	55.	56.	539.	571.	1138.	40.	14.	2414.	4.83
CONTINGENCY (20.0 %)	285.	294.	2804.	2971.	5917.	208.	73.	12551.	25.10
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	1884.	1884.	3.77
TOTAL FIXED INVESTMENT	1708.	1762.	16826.	17826.	35500.	1246.	7456.	82324.	164.65
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	171.	176.	1683.	1783.	3550.	125.	44.	7530.	15.06
INTEREST DURING CONSTRUCTION (15.6 %)	266.	275.	2625.	2781.	5538.	194.	1163.	12843.	25.69
ROYALTIES (1.0 %)	10.	11.	102.	108.	215.	8.	3.	455.	0.91
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	58.	59.	567.	601.	1197.	42.	285.	2810.	5.62
TOTAL CAPITAL INVESTMENT	2215.	2285.	21805.	23101.	46003.	1615.	9379.	106403.	212.81

Retrofit Option

The variable RETRO allows retrofit plant economics to be projected from the new plant economics using a factor supplied by the user.

Line No.	Input data
19	1 1.5 $\underset{\text{RETRO}}{\underset{\downarrow}{1.3}}$ 366.8 292.2 346.0

For new plants, RETRO should be set at 1.0. Regardless of whether RETRO is specified as 1.0 or greater than 1.0, the equipment lists are printed using the original new costs. When RETRO is specified to be greater than 1.0, the new equipment and ancillary costs in each processing area are multiplied by the retrofit factor and the area breakdown and direct process investment in the printed total capital investment table are the retrofit costs. All the remaining capital investment items, except land and landfill direct and indirect investment, are based on retrofit direct process investment. Also, the retrofit revenue requirement tables will reflect retrofit capital investment. (However, the user should note that the heat rate and economic factors are not automatically changed by use of this option. Appropriate factors must carefully be chosen by the user to yield correct raw material and energy consumption quantities, and thus correct operating costs.) An example illustrating the costs effects of using a retrofit factor of 1.3 is shown in Table 15.

TABLE 15. EXAMPLE RESULTS ILLUSTRATING THE COST EFFECTS OF USING A RETROFIT FACTOR

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED RETROFIT INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINUS 500 MW -- BASE -- 00010025

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	559.	501.	1783.	9072.	9663.	528.	89.	22195.	44.39
LABOR	288.	154.	83.	1220.	15914.	172.	101.	17933.	35.87
PIPING									
MATERIAL	0.	64.	0.	344.	0.	0.	0.	408.	0.82
LABOR	0.	86.	0.	122.	0.	0.	0.	208.	0.42
DUCTWORK									
MATERIAL	0.	0.	5547.	0.	0.	0.	0.	5547.	11.09
LABOR	0.	0.	3968.	0.	0.	0.	0.	3968.	7.94
FOUNDATIONS									
MATERIAL	19.	30.	67.	306.	139.	13.	6.	582.	1.16
LABOR	35.	58.	120.	549.	252.	24.	11.	1049.	2.10
STRUCTURAL									
MATERIAL	79.	17.	0.	0.	278.	6.	4.	383.	0.77
LABOR	22.	20.	0.	0.	413.	3.	1.	458.	0.92
ELECTRICAL									
MATERIAL	120.	141.	214.	110.	123.	103.	83.	894.	1.79
LABOR	66.	67.	814.	91.	50.	30.	20.	1139.	2.28
INSTRUMENTATION									
MATERIAL	26.	161.	52.	340.	204.	39.	11.	835.	1.67
LABOR	3.	19.	5.	52.	91.	12.	2.	183.	0.37
BUILDINGS									
MATERIAL	44.	0.	0.	704.	0.	0.	0.	748.	1.50
LABOR	18.	0.	0.	288.	0.	0.	0.	306.	0.61
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	64.	69.	575.	816.	781.	52.	15.	2369.	4.74
TOTAL RETROFIT PROCESS CAPITAL	1343.	1386.	13228.	14016.	27909.	982.	343.	59206.	118.41
SERVICES AND MISCELLANEOUS (6.0 %)	81.	83.	794.	841.	1675.	59.	21.	3552.	7.10
TOTAL RETROFIT DIRECT PROCESS INVESTMENT	1424.	1469.	14021.	14857.	29583.	1041.	363.	62758.	125.52
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2006.	2006.	4.01
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	65.	65.	0.13
TOTAL RETROFIT DIRECT INVESTMENT	1424.	1469.	14021.	14857.	29583.	1041.	3065.	65460.	130.92
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	100.	103.	981.	1040.	2071.	73.	25.	4393.	8.79
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	28.	29.	280.	297.	592.	21.	7.	1255.	2.51
CONSTRUCTION EXPENSES (16.0 %)	228.	235.	2243.	2377.	4733.	167.	58.	10041.	20.08
CONTRACTOR FEES (5.0 %)	71.	73.	701.	743.	1479.	52.	18.	3138.	6.28
CONTINGENCY (20.0 %)	370.	382.	3646.	3863.	7692.	271.	95.	16317.	32.63
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	929.	929.	1.86
TOTAL RETROFIT FIXED INVESTMENT	2221.	2291.	21873.	23176.	46150.	1624.	4198.	101533.	203.07
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	222.	229.	2187.	2318.	4615.	162.	57.	9790.	19.58
INTEREST DURING CONSTRUCTION (15.6 %)	346.	357.	3412.	3616.	7199.	253.	655.	15839.	31.68
ROYALTIES (1.0 %)	13.	14.	132.	140.	279.	10.	3.	592.	1.18
LAND (6000. $/ACRE)	2.	2.	4.	3.	4.	1.	429.	445.	0.89
WORKING CAPITAL	72.	75.	713.	756.	1505.	53.	156.	3331.	6.66
TOTAL RETROFIT CAPITAL INVESTMENT	2877.	2968.	28323.	30009.	59753.	2104.	5497.	131531.	263.06

(Continued)

TABLE 15. (Continued)

```
     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP

  PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINUS  500 MW

                                    DISPLAY SHEET FOR YEAR=    1
                                  ANNUAL OPERATION KW-HR/KW =  5500
                                                                                    TOTAL
                                                                                    ANNUAL
                                                ANNUAL QUANTITY      UNIT COST,$   COST,$
                                                ---------------      -----------   ------
        DIRECT COSTS
        ------------
          RAW MATERIAL
          ------------
            LIME                                   10.4 K TONS       90.00/TON       939000
                                                                                 ----------
              SUBTOTAL RAW MATERIAL                                                  939000

          CONVERSION COSTS
          ----------------
            OPERATING LABOR AND
              SUPERVISION                       31410.0 MAN-HR       19.00/MAN-HR    596700
            LANDFILL LABOR AND
              SUPERVISION                       24960.0 MAN-HR       24.00/MAN-HR    599000
            UTILITIES
              PROCESS WATER                    142670.0 K GAL         0.16/K GAL      22800
              ELECTRICITY                    34939710.0 KWH           0.055/KWH     1921700
              DIESEL FUEL                       48280.0 GAL           1.60/GAL        77300
            MAINTENANCE
              LABOR AND MATERIAL                                                    3846500
            ANALYSES                             5330.0 HR           26.00/HR        138600
                                                                                 ----------
              SUBTOTAL CONVERSION COSTS                                             7202600

              SUBTOTAL DIRECT COSTS                                                 8141600

        INDIRECT COSTS
        --------------
          OVERHEADS
            PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)   3108500
                                                                                 ----------
          FIRST YEAR OPERATING AND MAINTENANCE COSTS                               11250100
          LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)           20518800
                                                                                 ----------
              FIRST YEAR ANNUAL REVENUE REQUIREMENTS                               31768900

              EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)   11.55

              FIRST YEAR DOLLARS PER TON OF SULFUR REMOVED                          6847.53
-----------------------------------------------------------------------------------------------------------
          LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)  21217700
          LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)           20518800
                                                                                 ----------
              LEVELIZED ANNUAL REVENUE REQUIREMENTS                                41736500

              EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)   15.18

              LEVELIZED DOLLARS PER TON OF SULFUR REMOVED                           8995.96
-----------------------------------------------------------------------------------------------------------
        HEAT RATE  10500. BTU/KWH    -    HEAT VALUE OF COAL     8200 BTU/LB    -    COAL RATE   1760700 TONS/YR
```

USING THE MODEL

As previously discussed, a tape copy of the model can be obtained from TVA or TVA can make a limited number of specific runs based on user-supplied input data. This section is provided for potential users who may wish to obtain the model for independent use.

The model was developed for, and is executed on, the TVA IBM-370 computer system. The current model is a FORTRAN program written in FORTRAN77 language and compiled using a VS FORTRAN compiler. The model contains over 7,000 lines of source code. Core storage requirements for the model are about 400,000 bytes. No attempts are planned to overlay or otherwise reduce the size of the model.

The only input data required for model execution are the user input data; all other data for default assumptions and option-related calculations are assigned the necessary values internally within the program. Temporary online storage requirements depend on the number of cases to be run but typically do not exceed 200,000 bytes.

The model is designed for batch execution. A data file is created interactively (typically using a text editor); all variable values (including the options selected) are examined and corrected if necessary, then the model is executed (via a batch run submitted from the interactive terminal) and the input is processed as a standard data file.

This method of providing input data has been found to be preferable in most cases. When separate but similar model runs are required, the data file containing the input is copied to a second file, variables and options are modified as necessary, and a second model run is submitted. This reduces both input preparation time and the number of input data errors because only the variables and options that differ from a previous run must be modified.

The JCL required to execute the model in a batch mode using a procedure file is shown in Table 16. The catalogued procedure (Table 16) is executed and the required input is read from a previously created data file. The JCL examples shown in Table 16 generally apply whether the job is submitted interactively or with a card deck.

The amount of computer time required for model execution is a function of the number of cases of input data and the particular computer system. On the TVA system (AMDAHL V8 with JES3), the average CPU time required per case is about 0.5 second but some cases have exceeded 2 seconds.

TABLE 16. EXAMPLE JCL TO EXECUTE THE MODEL USING A PROCEDURE FILE

```
//TXSPADRY      JOB 123456,FSUDHOFF.CEBMS.2814,MSGLEVEL=1,CLASS=B,       000000
//                TIME=(,30),MSGCLASS=T,NOTIFY=$LALQ01                     000001
//*                                                                        000002
//*MAIN           ORG=RGROUP03                                             000003
//*                                                                        000004
//LIST1  EXEC     PGM=IO80X                                                000005
//SYSPRINT    DD SYSOUT=*                                                  000006
//SYSUT1      DD DSN=$LALQ01.GATOR.DATA(APPSAT),DISP=SHR                   000007
//SYSUT2      DD SYSOUT=*                                                  000008
//*                                                                        000009
//STEP1  EXEC     PGM=MODEL,REGION=400K                                    000010
//STEPLIB     DD DSN=$LALQ01.GATOR.LOAD,DISP=SHR                           000011
//FT05F001    DD DSN=$LALQ01.GATOR.DATA(APPSAT),DISP=SHR                   000012
//FT06F001    DD SYSOUT=*                                                  000013
//                                                                         000014
```

The model is usually distributed on magnetic tape for independent usage. A fairly wide range of tape format options is available but typically the tape is unlabeled, the density is 1600 BPI, and the block size is 4,000 characters (50 records, 80 characters per record).

MODEL STRUCTURE

As described previously, the overall model consists of one FORTRAN program capable of projecting the preliminary design and economics for a variety of spray dryer FGD systems. The model consists of a main program and 33 subroutines. An alphabetical listing of the subroutines in this program with a general description of their function is shown in Table 17. Since the subroutines are not executed in either alphabetical order or the order in which they occur in the program, a hierarchy chart showing the sequence for calling the various subroutines during batch program execution and identifying the main program and subroutines from which they are called is shown in Table 18.

Further documentation of the overall model is beyond the scope of this manual.

TABLE 17. ALPHABETICAL LISTING OF THE SUBROUTINES IN THE LIME SPRAY DRYER MODEL IDENTIFYING THE FUNCTION OF EACH SUBROUTINE

Model subroutines	Function
AREA1	Calculates design and cost for material-handling equipment
AREA2	Calculates design and cost for feed preparation equipment
AREA3	Calculates design and cost for gas-handling equipment
AREA4	Calculates design and cost for spray drying area equipment
AREA5	Calculates design and cost for particulate removal equipment
AREA6	Calculates design and cost for spray dryer solids-handling equipment
AREA7	Calculates design and cost for baghouse solids recycle equipment
ELECTR	Calculates design and cost of electrical motors, wiring, and conduit
GASFLO	Calculates material balance for flue gas streams
HOTGAS	Calculates flow rate, composition for gas streams base
INTER	Calculates interest during construction
LANDP	Prints material balance, design, and cost of FGD landfill
LEVEL	Calculates levelized capital charges and lifetime levelizing factor
MATBAL	Calculates the material balance using iterative convergence
NSPS	Calculates allowable emissions based on 1979 NSPS
PLANT	Calculates land required for spray dryer FGD process
PRINT	Prints all material balance and FGD equipment costs
PRINTI	Prints spray dryer FGD investment summary table
PROGM2	Initializes arrays for lifetime cost projections
PRTALF	Prints first-year annual revenue requirements table
PRTASF	Prints short form of first-year annual revenue requirements
PRTBLF	Prints titles for lifetime revenue requirements table
PRTCLF	Prints lifetime revenue requirements projections
PRTDLF	Prints summation of lifetime revenue requirements
READIN	Reads from unit 5 all input data to the model
REVCAL	Calculates revenue requirements projections
REVHEAD	Creates revenue requirements table headings
REVCON	Converts selected variables from single to double precision
SATTEM	Calculates the flue gas saturation temperature
SCLAND	Calculates landfill design
SPRINT	Prints short-form spray dryer FGD investment summary
TOTALS	Sums costs for all components of spray dryer FGD system
WORKCP	Calculates working capital component of FGD costs

TABLE 18. HIERARCHY CHART FOR EXECUTION OF THE LIME SPRAY DRYER COMPUTER MODEL IN THE BATCH MODE

```
CALL READIN
CALL LEVEL
CALL INTER
CALL HOTGAS
CALL NSPS
CALL SATTEM
CALL MATBAL
CALL AREA1
CALL AREA2
CALL GASFLO
CALL AREA3
CALL AREA4
CALL AREA5
CALL AREA6
CALL AREA7
CALL ELECTR
CALL PRINT
CALL SCLAND
    CALL LANDP
CALL TOTALS
    CALL PLANT
    CALL WORKCP
CALL PRINTI
    CALL SPRINT
CALL REVCON
CALL REVCAL
    CALL RVHEAD
    CALL PRTALF
    CALL PRTASF
    CALL PROGM2
        CALL PRTBLF
        CALL PRTCLF
        CALL PRTDLF
```

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Appendix A

PROCESS FLOWSHEET

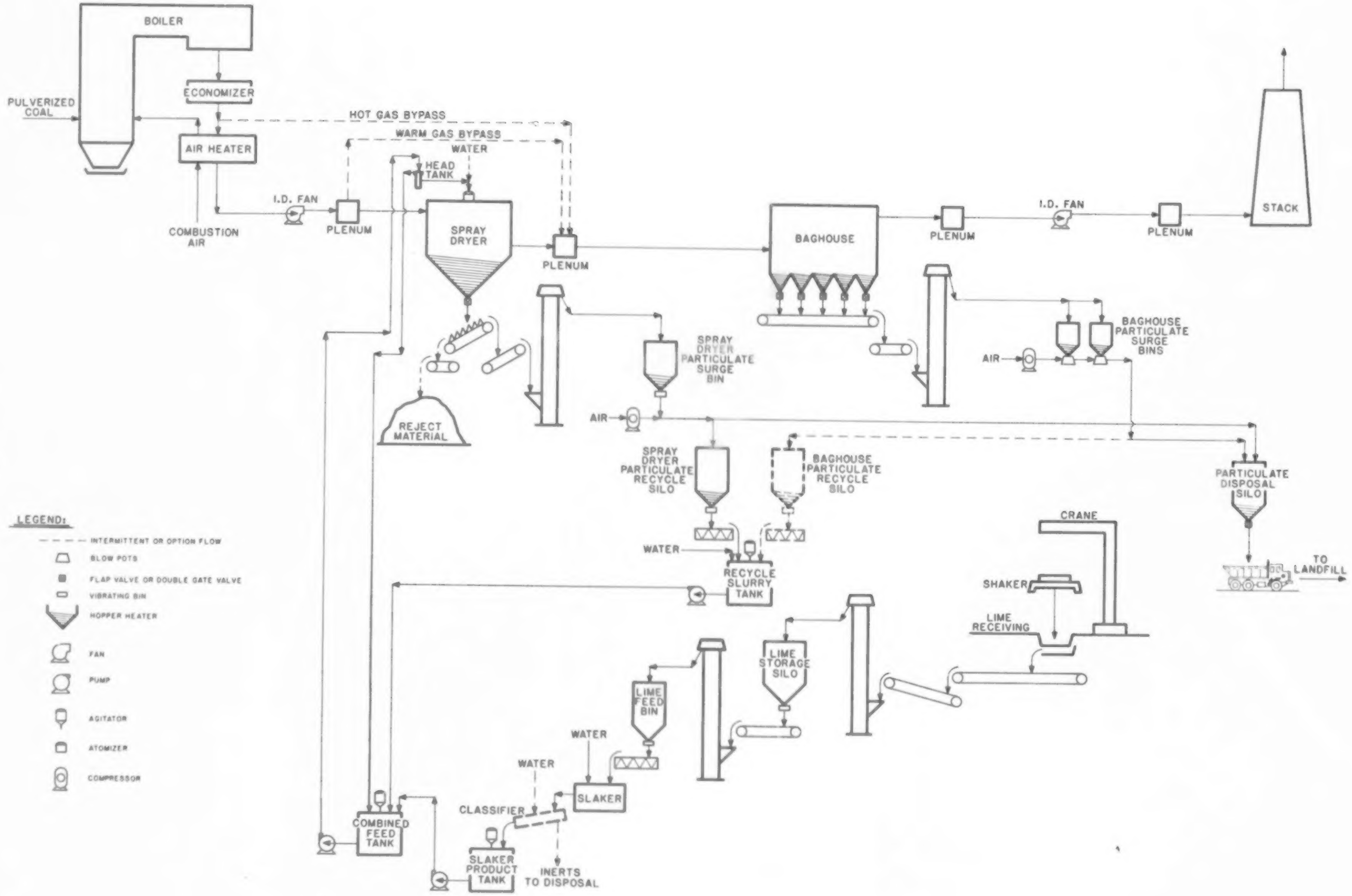
BOILER
PULVERIZED COAL
ECONOMIZER
AIR HEATER
COMBUSTION AIR
HOT GAS BYPASS
WARM GAS BYPASS
WATER
HEAD TANK
I.D. FAN
PLENUM
SPRAY DRYER
PLENUM
REJECT MATERIAL
SPRAY DRYER PARTICULATE SURGE BIN
AIR
BAGHOUSE
PLENUM
I.D. FAN
PLENUM
STACK
BAGHOUSE PARTICULATE SURGE BINS
AIR
SPRAY DRYER PARTICULATE RECYCLE SILO
BAGHOUSE PARTICULATE RECYCLE SILO
WATER
RECYCLE SLURRY TANK
PARTICULATE DISPOSAL SILO
TO LANDFILL
CRANE
SHAKER
LIME RECEIVING
LIME STORAGE SILO
LIME FEED BIN
WATER
SLAKER
WATER
CLASSIFIER
INERTS TO DISPOSAL
SLAKER PRODUCT TANK
COMBINED FEED TANK
LEGEND:
INTERMITTENT OR OPTION FLOW
BLOW POTS
FLAP VALVE OR DOUBLE GATE VALVE
VIBRATING BIN
HOPPER HEATER
FAN
PUMP
AGITATOR
ATOMIZER
COMPRESSOR

Figure A-1. Lime spray dryer process. Flow diagram.

Appendix B

DESIGN AND ECONOMIC PREMISES FOR EMISSION CONTROL EVALUATIONS

DESIGN AND ECONOMIC PREMISES FOR EMISSION CONTROL EVALUATIONS

INTRODUCTION

These premises provide criteria for economic evaluations of emission control and related processes for electric utility power plants fired with pulverized coal. The design premises define representative coal and power unit conditions and emission control design practices. The economic premises are based on regulated utility economics; they prescribe procedures for determining capital investments and annual revenue requirements. The premises are directly applicable to economic evaluations of coal cleaning; flue gas desulfurization (FGD), nitrogen oxides (NO_x), and fly ash control; bottom ash handling; and ponding or landfill disposal of nonhazardous wastes.

The economic evaluations assume a conceptual design based on the design premises and are developed from engineering data such as flow diagrams, material balances, and equipment costs. Depending on the degree of accuracy specified, some costs are either scaled or developed from detailed design and operating data.

A new 500-MW power unit is used as the base case size. Seven coals, representing typical steam coals used in the United States, are defined. The western subbituminous coal containing 0.7% sulfur and 4% ash (moisture-free basis) is used as the base case coal. The other coals represent eastern bituminous coals with different sulfur contents, western bituminous coals, and lignite.

These premises, updated in late 1983, are based on 1985 costs for capital investment and 1987 costs for annual revenue requirements. The cost basis and other premise criteria are updated periodically; usually the entire premise criteria are updated at one time rather than on a piecemeal basis to maintain the comparability of evaluations made over a period of time. The revision of the cost basis from 1983 to 1985 dollars for the capital investment and from 1984 to 1987 dollars for the annual revenue requirements is the only major change from the previous premises, which have been used since April 1980. The other changes are relatively minor revisions to the design premises: gaseous emission of 95% instead of 92% of the sulfur in eastern bituminous coals, updated spray dryer FGD designs, and a slightly modified landfill design.

DESIGN PREMISES

The design premises specify the coal properties; power unit conditions; emission control requirements; design features of NO_x, SO_2, and fly ash control processes; and waste-handling and disposal methodology.

COAL PREMISES

The premise coals consist of four eastern bituminous coals containing 5.0%, 3.5%, 2.0%, and 0.7% sulfur; a 0.7% sulfur western bituminous coal; a 0.7% sulfur western subbituminous coal; and a 0.9% sulfur North Dakota lignite. They are based on analyses of U.S. steam coals representative of the types in current use (7,8). The analysis data for each of these coals are summarized in Table B-1 and a fly ash analysis for each coal is shown in Table B-2.

TABLE B-2. FLY ASH COMPOSITIONS

Component	Bituminous fly ash, wt %	Subbituminous fly ash, wt %	Lignite fly ash, wt %
SiO_2	50.8	39.7	23.0
Al_2O_3	20.6	21.5	11.5
TiO_2	2.5	1.1	0.5
Fe_2O_3	16.9	7.4	8.6
CaO	2.0	20.0	21.6
MgO	1.0	4.7	6.0
Na_2O	0.4	1.7	5.9
K_2O	2.6	0.5	0.5
SO_3	2.4	2.3	19.2
P_2O_5	-	1.0	0.4
Other	0.8	0.1	2.8
Total	100.0	100.0	100.0

TABLE B-1. COMPOSITION OF PREMISE COALS

Coal	Sulfur: Total, %	Sulfur: Pyritic, %	Sulfur: Sulfatic, %	Sulfur: Organic, %	Ash, %	Moisture, %	Heat content, Btu/lb	Ultimate analysis: C, %	Ultimate analysis: H, %	Ultimate analysis: O, %	Ultimate analysis: N, %	Ultimate analysis: Cl, %
(As-fired basis)												
Eastern bituminous, 5.0% S	4.80	3.17	0.05	1.58	15.10	4.0	11,700	65.2	4.0	5.5	1.3	0.1
Eastern bituminous, 3.5% S	3.36	2.21	0.05	1.10	15.14	4.0	11,700	66.7	3.8	5.6	1.3	0.1
Eastern bituminous, 2.0% S	1.92	1.25	0.04	0.63	15.08	4.0	11,700	67.8	3.7	6.0	1.4	0.1
Eastern bituminous, 0.7% S	0.67	0.44	0.01	0.22	15.13	4.0	11,700	68.8	3.6	6.3	1.4	0.1
Western bituminous, 0.7% S	0.59	0.20	0.01	0.38	9.71	16.0	9,700	57.0	3.9	11.5	1.2	0.1
Western subbituminous, 0.7% S (Powder River Basin)	0.48	0.16	0.01	0.31	6.30	29.3	8,200	49.0	3.5	10.7	0.7	0.02
North Dakota lignite, 0.9% S	0.57	0.19	0.01	0.37	7.22	36.3	6,600	40.1	2.8	12.4	0.6	0.01
(Moisture-free basis)												
Eastern bituminous, 5.0% S	5.00	3.30	0.05	1.65	15.7			67.9	4.2	5.7	1.4	0.1
Eastern bituminous, 3.5% S	3.50	2.30	0.05	1.15	15.7			69.5	4.0	5.8	1.4	0.1
Eastern bituminous, 2.0% S	2.00	1.31	0.04	0.65	15.7			70.6	3.9	6.3	1.4	0.1
Eastern bituminous, 0.7% S	0.70	0.46	0.01	0.23	15.7			71.7	3.8	6.6	1.4	0.1
Western bituminous, 0.7% S	0.70	0.24	0.01	0.45	11.6			67.9	4.6	13.7	1.4	0.1
Western subbituminous, 0.7% S (Powder River Basin)	0.68	0.23	0.01	0.44	8.9			69.3	5.0	15.1	1.0	0.02
North Dakota lignite, 0.9% S	0.89	0.30	0.01	0.58	11.3			63.0	4.4	19.5	0.9	0.01

As-fired coal refers to the coal entering the coal-cleaning plant or power plant. This coal is supplied in a 3-inch top size after large rocks and trash have been removed from the run-of-mine coal. Broken coal is assumed to have the particle size distributions represented by the Bennett form of the Rosin and Rammler equation,

$$R = 100e^{-(x/\bar{x})^n}$$

which can be plotted on special graph paper devised by the U.S. Bureau of Mines (BOM) (9) as shown in Figure B-1. In the equation,

R = the weight percentage of coal retained on a screen whose aperture is x. R expresses cumulative oversize and is the ordinate in Figure B-1.

e = the base of the natural logarithm.

x = particle diameter or width of screen aperture in millimeters. It is the abscissa in Figure B-1.

$\bar{x}$ = a size constant, in millimeters, that is specific to each distribution line of particle size. In Figure B-1, it is the value of x when $R = 36.79\%$; in turn $R = 36.79\%$ when $\bar{x} = x$ in the Rosin and Rammler equation.

n = a size distribution constant. In Figure B-1, it is the arithmetical slope of a distribution line. Parallel distribution lines have the same value of n.

For all distribution lines in Figure B-1, the value of n is 0.8840. Values of $\bar{x}$ for selected size distributions are given below.

Nominal top sizes	Actual aperture size (Tyler 2 series) in.	Actual aperture size (Tyler 2 series) mm	$\bar{x}$ mm
3 in.	2.970	75.43	13.40
2 in.	2.100	53.34	9.478
1-1/2 in.	1.485	37.71	6.702
3/4 in.	0.742	18.86	3.351
3/8 in.	0.371	9.429	1.676
3 mesh	0.093	2.357	0.4189
14 mesh	0.046	1.179	0.2094
28 mesh	0.023	0.589	0.1047

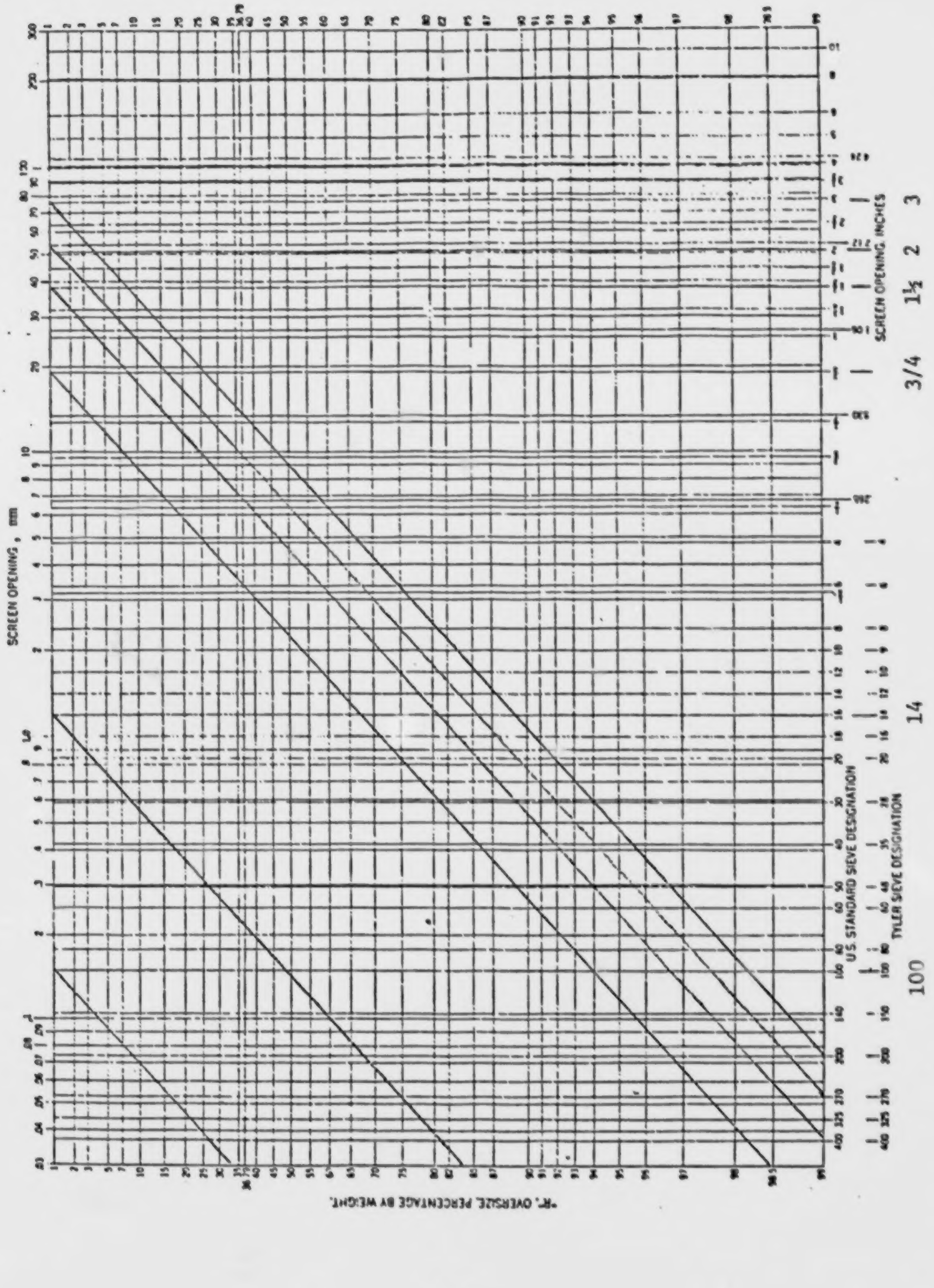

Figure B-1. Rosin-Rammler plots of premise coal sizes.

POWER PLANT

The power plant site is assumed to be in the north-central region (Illinois, Indiana, Ohio, Michigan, Kentucky, and Wisconsin). The location represents an area in which coal-fired power plants burning coals of diverse type and source are situated (10). The design is based on standard design practices (11,12) and current trends in utility boiler construction (13). The base case power unit is a new, single 500-MW, balanced-draft, dry-bottom boiler fired with pulverized coal. The steam pressure is 2,400 psi. The superheat and reheat temperatures are 1,000°F.

Power unit size case variations consist of similar 200-MW and 1,000-MW units. For new units, the systems being evaluated are assumed to be installed during construction of the power plant. New units are assumed to have a 30-year life and to operate at full load for 5,500 hours/yr. For case variations, identical existing units with 20 years of remaining life at 5,500 hours/yr of full-load operation are used. The heat rates are shown in Table B-3. They are based on coal type, unit size, and unit age. To provide for equitable comparisons, the power units are not derated for energy consumption by the systems evaluated. Instead, the energy requirements are charged as independently purchased commodities. Normally, cost estimates are based on a single power unit independent of other units at the site. In cases in which a plant-wide process or system is evaluated, a plant capacity of 1,000 MW is normally used.

TABLE B-3. POWER UNIT HEAT RATE

	New			Existing		
Power unit size, MW:	200	500	1,000	200	500	1,000
Remaining life, yr	30	30	30	20	20	20
Full load, hr/yr	5,500	5,500	5,500	5,500	5,500	5,500
Heat rate, Btu/kWh						
Bituminous coal	9,700	9,500	9,200	9,900	9,700	9,500
Subbituminous coal	10,700	10,500	10,200	11,000	10,700	10,500
Lignite	11,200	11,000	10,700	11,400	11,200	11,000

FLUE GAS COMPOSITIONS

Flue gas compositions are based on combustion of pulverized coal assuming a total air rate equivalent to 139% of the stoichiometric requirement (defined as air for combustion of carbon, hydrogen, and sulfur). This includes 20% excess air to the boiler and 19% additional air leakage to the flue gas in the air heater. It is assumed that 80% of the ash present in all coals is emitted as fly ash. Sulfur emitted is dependent on the coal type; 95% of the sulfur in all eastern coals and 85% of the sulfur in all western coals and lignite are emitted as gaseous sulfur oxides (SO_x). The remaining sulfur is removed in the bottom ash and fly ash. No loss of sulfur in the pulverizers is assumed. Three percent of the sulfur emitted as SO_x is SO_3 and the remainder is SO_2.

A flow diagram around the boiler is shown in Figure B-2 and detailed boiler material balances and flue gas composition summaries for stream 8, for each premise coal, are shown in Tables B-4 through B-17. The streams shown in the material balances have excess significant digits for cases in which higher accuracy is needed.

ENVIRONMENTAL REGULATIONS

Emissions from new coal-fired utility plants are regulated by the new source performance standards (NSPS), which are promulgated by the U.S. Environmental Protection Agency (EPA) under authority of the Clean Air Act as amended in 1970 and 1977 (14). This section requires EPA to set Federal emission limitations that reflect the degree of control that can be achieved by using the best available control technology (BACT). In 1971, EPA issued NSPS to limit emissions of SO_2, NO_x, and particulate matter from utility power plants (15). The 1971 NSPS specify a maximum emission based on heat input of 0.10 lb/MBtu for particulate matter and 1.2 lb/MBtu for SO_2. They apply to power units, for which construction began between August 1971 and September 1978. In 1979, EPA revised the NSPS (16) as shown in Table B-18. The controlled outlet SO_2 emission and SO_2 removal efficiencies for the premise coals are shown in Figure B-3 and tabulated in Table B-19.

Equation to determine equivalent SO_2 content of coal:

$$E = (S/H)(2 \times 10^4)$$

where: E = equivalent SO_2 content of coal, lb SO_2/MBtu (as fired)

S = sulfur content of coal, wt % (as fired)

H = heat content of coal, Btu/lb (as fired)

Equations to determine overall % sulfur removal required

$E < 2.0$

70% equivalent SO_2 removal required

$2.0 \leq E < 6.0$

% equivalent SO_2 removal required = $((E - 0.6)/E)(100)$

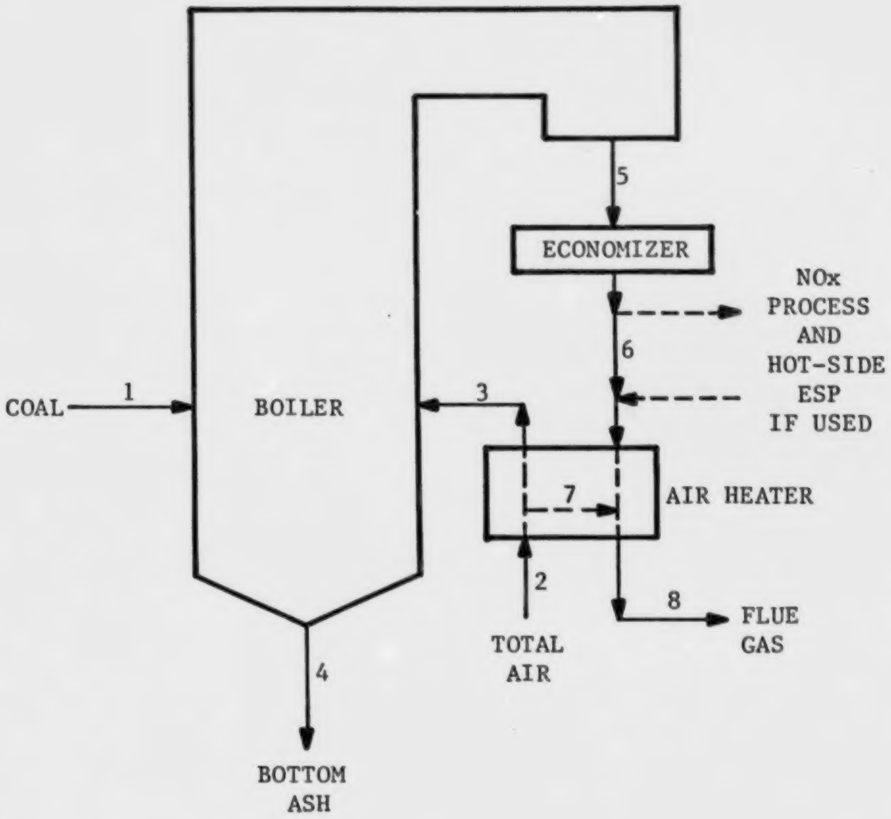
COAL
1
BOILER
3
5
ECONOMIZER
NOx
PROCESS
AND
HOT-SIDE
ESP
IF USED
6
AIR HEATER
7
2
TOTAL
AIR
8
FLUE
GAS
4
BOTTOM
ASH

Figure B-2. Boiler flow diagram.

TABLE B-4. BOILER MATERIAL BALANCE FOR
5% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,047,807	4,357,819	12,455
Flow rate, sft^3/min @ 60^{o}F		1,115,166	962,733	
Temperature, ^{o}F		80		
N_2 (C) lb/hr	(264,701)	3,829,456	3,306,006	
O_2 (H) lb/hr	(16,239)	1,153,571	995,888	
CO_2 (O) lb/hr	(22,329)			
SO_2 (N) lb/hr	(5,278)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(19,487)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	64,799	55,925	
Ash lb/hr	61,303			12,455

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,751,973	4,751,973	689,988	5,441,961
Flow rate, sft^3/min @ 60^{o}F	999,502	999,502	152,433	1,151,935
Temperature, ^{o}F				
N_2 lb/hr	3,310,415	3,310,415	523,451	3,833,866
O_2 lb/hr	164,941	164,941	157,682	322,623
CO_2 lb/hr	969,982	969,982		969,982
SO_2 lb/hr	35,915	35,915		35,915
SO_3 lb/hr	1,388	1,388		1,388
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	217,184	217,184	8,855	226,039
Ash	49,822	49,822		49,822

TABLE B-5. FLUE GAS COMPOSITION FOR 5% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.12	136,900	3,834,000
O_2	5.53	10,080	322,600
CO_2	12.10	22,040	970,000
SO_2	0.31 (3,076 ppm)	561	35,920
SO_3	0.01 (96 ppm)	17	1,388
NO	0.03 (324 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.89	12,550	226,000
	100.00	182,200	5,392,000
Fly ash[a]			49,820
Total			5,442,000

Sft3/min (60°F) = 1,152,000
Aft3/min (300°F) = 1,684,000

Fly Ash Loading

	Gr/sft3
Wet	5.04
Dry	5.42

Sulfuric acid dewpoint temperature: 316°F

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[a] See Table B-2 for fly ash composition.

EPA Form 2350-4 (4-80)
(PREVIOUSLY CIN: EPA FORM 287)
TYPING GUIDE SHEET

TABLE B-6. BOILER MATERIAL BALANCE FOR

3.5% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,071,690	4,378,438	12,430
Flow rate, sft^3/min @ 60°F		1,120,442	967,288	
Temperature, °F		80		
N_2 (C) lb/hr	(270,791)	3,847,575	3,321,648	
O_2 (H) lb/hr	(15,427)	1,159,029	1,000,601	
CO_2 (O) lb/hr	(22,735)			
SO_2 (N) lb/hr	(5,278)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(13,641)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,086	56,189	
Ash lb/hr	61,466			12,430

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,772,430	4,772,430	693,252	5,465,682
Flow rate, sft^3/min @ 60°F	1,002,880	1,002,880	153,154	1,156,034
Temperature, °F				
N_2 lb/hr	3,326,058	3,326,058	525,927	3,851,985
O_2 lb/hr	165,726	165,726	158,428	324,154
CO_2 lb/hr	992,298	992,298		992,298
SO_2 lb/hr	25,140	25,140		25,140
SO_3 lb/hr	972	972		972
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	210,192	210,192	8,879	219,089
Ash lb/hr	49,718	49,718		49,718

TABLE B-7. FLUE GAS COMPOSITION

FOR 3.5% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.21	137,500	3,852,000
O_2	5.54	10,130	324,200
CO_2	12.33	22,550	992,300
SO_2	0.22 (2,149 ppm)	393	25,140
SO_3	0.01 (68 ppm)	12	972
NO	0.03 (323 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.65	12,160	219,100
	100.00	182,800	5,416,000
Fly ash[a]			49,720
Total			5,466,000

Sft^3/min (60°F) = 1,156,000
Aft^3/min (300°F) = 1,690,000

Fly Ash Loading

	Gr/sft^3
Wet	5.02
Dry	5.38

Sulfuric acid dewpoint temperature: 308°F

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a. See Table B-2 for fly ash composition.

EPA Form 2350-4 (4-80)

TYPING GUIDE SHEET

TABLE B-8. BOILER MATERIAL BALANCE FOR

2% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Air to furnace	Bottom ash
Total stream, lb/hr	405,983	5,081,446	4,386,860	12,322
Flow rate, sft^3/min @ 60°F	406,000	1,122,597	969,149	
Temperature, °F		80		
N_2 (C) lb/hr	(275,256)	3,854,977	3,328,038	
O_2 (H) lb/hr	(15,021)	1,161,258	1,002,525	
CO_2 (O) lb/hr	(24,359)			
SO_2 (N) lb/hr	(5,684)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(7,795)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,211	56,297	
Ash lb/hr	61,223			12,322

Stream No.	5	6	7	8
Description	Flue gas to economizer	Flue gas to air heater	Air inleakage	Flue gas from air heater
Total stream, lb/hr	4,780,772	4,780,772	694,586	5,475,358
Flow rate, sft^3/min @ 60°F	1,004,532	1,004,532	153,449	1,157,981
Temperature, °F	800	705	535	300
N_2 lb/hr	3,332,854	3,332,854	526,939	3,859,793
O_2 lb/hr	166,047	166,047	158,733	324,780
CO_2 lb/hr	1,008,662	1,008,662		1,008,662
SO_2 lb/hr	14,366	14,366		14,366
SO_3 lb/hr	555	555		555
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	206,672	206,672	8,914	215,586
Ash lb/hr	49,290	49,290		49,290

TABLE B-9. FLUE GAS COMPOSITION

FOR 2% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.24	137,800	3,860,000
O_2	5.54	10,100	324,800
CO_2	12.52	22,920	1,009,000
SO_2	0.12 (1,225 ppm)	224	14,400
SO_3	0.00 (39 ppm)	7	555
NO	0.03 (322 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (66 ppm)	12	418
H_2O	6.54	11,970	215,600
	100.00	183,100	5,427,000
Fly ash[a]			49,240
Total			5,475,000

Sft3/min (60°F) = 1,158,000
Aft3/min (300°F) = 1,692,000

Fly Ash Loading

	Gr/sft3
Wet	4.96
Dry	5.30

Sulfuric acid dewpoint temperature: 297°F

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[a] See Table B-2 for fly ash composition.

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TABLE B-10. BOILER MATERIAL BALANCE FOR 0.7% SULFUR EASTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	405,983	5,091,465	4,395,510	12,312
Flow rate, sft^3/min @ 60^{o}F		1,124,811	971,060	
Temperature, ^{o}F		80		
N_2 (C) lb/hr	(279,316)	3,862,577	3,334,599	
O_2 (H) lb/hr	(14,616)	1,163,548	1,004,502	
CO_2 (O) lb/hr	(25,577)			
SO_2 (N) lb/hr	(5,684)			
SO_3 (Cl) lb/hr	(406)			
NO (S) lb/hr	(2,720)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	16,239	65,340	56,409	
Ash lb/hr	61,425			12,312

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,789,268	4,789,268	695,955	5,485,223
Flow rate, sft^3/min @ 60^{o}F	1,006,060	1,006,C60	153,751	1,159,811
Temperature, ^{o}F	800	705	535	300
N_2 lb/hr	3,339,415	3,339,415	527,978	3,867,393
O_2 lb/hr	166,376	166,376	159,046	325,422
CO_2 lb/hr	1,023,540	1,023,540		1,023,540
SO_2 lb/hr	5,013	5,013		5,013
SO_3 lb/hr	194	194		194
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	418	418		418
H_2O lb/hr	203,155	203,155	8,931	212,086
Ash	49,249	49,249		49,249

TABLE B-11. FLUE GAS COMPOSITION

FOR 0.7% SULFUR EASTERN BITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	75.27	138,100	3,867,000
O_2	5.55	10,170	325,400
CO_2	12.68	23,260	1,024,000
SO_2	0.04 (428 ppm)	78	5,013
SO_3	0.00 (11 ppm)	2	194
NO	0.03 (322 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (65 ppm)	12	418
H_2O	6.42	11,770	212,100
	100.00	183,400	5,436,000
Fly ash[a]			49,250
Total			5,485,000

Sft^3/min (60°F) = 1,160,000
Aft^3/min (300°F) = 1,695,000

Fly Ash Loading

	Gr/sft^3
Wet	4.95
Dry	5.29

Sulfuric acid dewpoint temperature: 273°F

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[a] See Table B-2 for fly ash composition.

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TABLE B-12. BOILER MATERIAL BALANCE FOR

0.7% SULFUR WESTERN BITUMINOUS COAL

Stream No.	1	2	3	4
Description	Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr	489,691	5,117,371	4,417,874	9,596
Flow rate, sft^3/min @ 60^{o}F		1,130,534	976,000	
Temperature, ^{o}F		80		
N_2 (C) lb/hr	(279,124)	3,882,231	3,351,566	
O_2 (H) lb/hr	(19,098)	1,169,468	1,009,613	
CO_2 (O) lb/hr	(56,314)			
SO_2 (N) lb/hr	(5,876)			
SO_3 (Cl) lb/hr	(490)			
NO (S) lb/hr	(2,889)			
NO_2 lb/hr				
HCl lb/hr				
H_2O lb/hr	78,351	65,672	56,695	
Ash lb/hr	47,549			9,596

Stream No.	5	6	7	8
Description	Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr	4,897,968	4,897,968	699,498	5,597,466
Flow rate, sft^3/min @ 60^{o}F	1,045,965	1,045,965	154,534	1,200,499
Temperature, ^{o}F				
N_2 lb/hr	3,356,574	3,356,574	530,666	3,887,240
O_2 lb/hr	167,228	167,228	159,855	327,083
CO_2 lb/hr	1,022,834	1,022,834		1,022,834
SO_2 lb/hr	4,760	4,760		4,760
SO_3 lb/hr	184	184		184
NO lb/hr	1,766	1,766		1,766
NO_2 lb/hr	142	142		142
HCl lb/hr	504	504		504
H_2O lb/hr	305,590	305,590	8,977	314,567
Ash	38,386	38,386		38,386

TABLE B-13. FLUE GAS COMPOSITION
FOR 0.7% SULFUR WESTERN BITUMINOUS COAL
(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	73.10	138,800	3,887,000
O_2	5.38	10,220	327,100
CO_2	12.24	23,240	1,023,000
SO_2	0.04 (390 ppm)	74	4,760
SO_3	0.00 (10 ppm)	2	184
NO	0.03 (311 ppm)	59	1,766
NO_2	0.00 (16 ppm)	3	142
HCl	0.01 (74 ppm)	14	504
H_2O	9.20	17,460	314,600
	100.00	189,800	5,559,000
Fly ash[a]			38,390
Total			5,597,000

Sft^3/min (60°F) = 1,200,000
Aft^3/min (300°F) = 1,755,000

Fly Ash Loading

	Gr/sft^3
Wet	3.73
Dry	4.11

Sulfuric acid dewpoint temperature: 278°F

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[a] See Table B-2 for fly ash composition.

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TABLE B-14. BOILER MATERIAL BALANCE FOR

0.7% SULFUR WESTERN SUBBITUMINOUS COAL

Stream No.			1	2	3	4
Description			Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr			640,244	5,765,154	4,977,111	8,159
Flow rate, sft^3/min @ 60°F				1,273,643	1,099,548	
Temperature, °F				80		
N_2	(C)	lb/hr	(313,720)	4,373,663	3,775,824	
O_2	(H)	lb/hr	(22,409)	1,317,506	1,137,415	
CO2	(O)	lb/hr	(68,506)			
SO_2	(N)	lb/hr	(4,482)			
SO_3	(Cl)	lb/hr	(128)			
NO	(S)	lb/hr	(3,073)			
NO_2		lb/hr				
HCl		lb/hr				
H_2O		lb/hr	187,591	73,985	63,872	
Ash		lb/hr	40,335			8,159

Stream No.		5	6	7	8
Description		Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr		5,609,196	5,609,196	788,043	6,397,239
Flow rate, sft^3/min @ 60°F		1,215,098	1,215,098	174,095	1,389,193
Temperature, °F					
N_2	lb/hr	3,779,506	3,779,506	597,839	4,377,345
O_2	lb/hr	188,611	188,611	180,091	368,702
CO_2	lb/hr	1,149,608	1,149,608		1,149,608
SO_2	lb/hr	5,063	5,063		5,063
SO_3	lb/hr	196	196		196
NO	lb/hr	1,627	1,627		1,627
NO_2	lb/hr	131	131		131
HCl	lb/hr	132	132		132
H_2O	lb/hr	451,685	451,685	10,113	461,798
Ash	lb/hr	32,637	32,637		32,637

TABLE B-15. FLUE GAS COMPOSITION

FOR 0.7% SULFUR WESTERN SUBBITUMINOUS COAL

(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	71.13	156,300	4,377,000
O_2	5.25	11,520	368,700
CO_2	11.89	26,120	1,150,000
SO_2	0.04 (360 ppm)	79	5,063
SO_3	0.00 (9 ppm)	2	196
NO	0.02 (246 ppm)	54	1,627
NO_2	0.00 (14 ppm)	3	131
HCl	0.00 (18 ppm)	4	132
H_2O	11.67	25,630	461,800
	100.00	219,700	6,365,000
Fly ash[a]			32,640
Total			6,397,000

Sft3/min (60°F) = 1,389,000
Aft3/min (300°F) = 2,030,000

Fly Ash Loading

	Gr/sft3
Wet	2.74
Dry	3.10

Sulfuric acid dewpoint temperature: 280°F

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[a] See Table B-2 for fly ash composition.

TABLE B-16. BOILER MATERIAL BALANCE FOR 0.9% SULFUR NORTH DAKOTA LIGNITE

Stream No.			1	2	3	4
Description			Coal to boiler	Total air to air heater	Combustion air to boiler	Bottom ash
Total stream, lb/hr			833,333	5,938,178	5,126,485	12,176
Flow rate, sft^3/min @ 60°F				1,311,867	1,132,547	
Temperature, °F				80		
N_2	(C)	lb/hr	(334,167)	4,504,926	3,889,145	
O2	(H)	lb/hr	(23,333)	1,357,047	1,171,551	
CO_2	(O)	lb/hr	(103,333)			
SO_2	(N)	lb/hr	(5,000)			
SO_3	(Cl)	lb/hr	(83)			
NO	(S)	lb/hr	(4,750)			
NO_2		lb/hr				
HCl		lb/hr				
H_2O		lb/hr	302,500	76,205	65,789	
Ash			60,167			12,176

Stream No.		5	6	7	8
Description		Gas to economizer	Gas to air heater	Air inleakage	Gas to electrostatic precipitator
Total stream, lb/hr		5,947,642	5,947,642	811,693	6,759,335
Flow rate, sft^3/min @ 60°F		1,296,872	1,296,872	179,320	1,476,192
Temperature, °F		800			
N_2	lb/hr	3,893,140	3,893,140	615,780	4,508,920
O_2	lb/hr	194,053	194,053	185,496	379,549
CO_2	lb/hr	1,224,537	1,224,537		1,224,537
SO_2	lb/hr	7,825	7,825		7,825
SO_3	lb/hr	302	302		302
NO	lb/hr	2,045	2,045		2,045
NO_2	lb/hr	165	165		165
HCl	lb/hr	86	86		86
H_2O	lb/hr	576,786	576,786	10,417	587,203
Ash	lb/hr	48,703	48,703		48,703

TABLE B-17. FLUE GAS COMPOSITION
FOR 0.9% SULFUR NORTH DAKOTA LIGNITE
(Stream 8; gas to electrostatic precipitator)

Component	Volume, %	Lb-mol/hr	Lb/hr
N_2	68.95	161,000	4,509,000
O_2	5.08	11,860	379,500
CO_2	11.92	27,820	1,225,000
SO_2	0.05 (524 ppm)	122	7,825
SO_3	0.00 (17 ppm)	4	302
NO	0.03 (291 ppm)	68	2,045
NO_2	0.00 (17 ppm)	4	165
HCl	0.00 (9 ppm)	2	86
H_2O	13.97	32,600	587,200
	100.00	233,400	6,711,000
Fly ash[a]			48,700
Total			6,759,000

Sft3/min (60°F) = 1,476,000
Aft3/min (300°F) = 2,158,000

Fly Ash Loading

	Gr/sft3
Wet	3.85
Dry	4.47

Sulfuric acid dewpoint temperature: 295°F

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a. See Table B-2 for fly ash composition.

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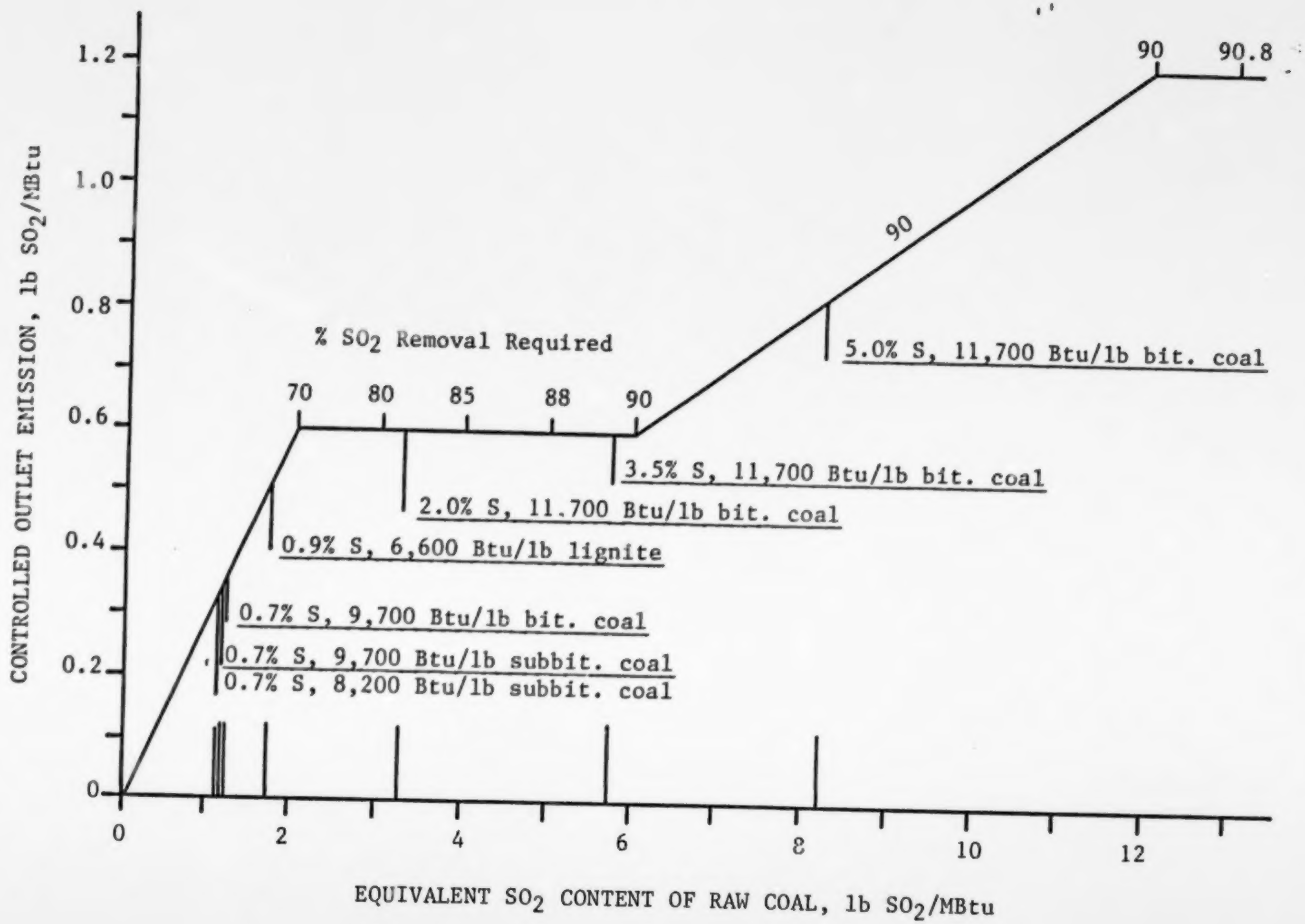

Figure B-3. Controlled SO_2 emission requirements for 1979 NSPS. Premise coals, shown underlined, are based on premise boiler conditions.

$6.0 \leq E < 12.0$

90% equivalent SO_2 removal required

$E \geq 12.0$

% equivalent SO_2 removal required = ((E - 1.2)/E)(100)

Equation to determine equivalent SO_2 removal required

% equivalent SO_2 removal required = ((A - B)/(1.0 - B))(100)

where: A = overall removal efficiency, decimal fraction
B = decimal fraction of S removed with ash: (1.0 - decimal fraction of sulfur emitted as SO_x)

TABLE B-18. 1979 NSPS EMISSION STANDARDS (16)

SO_2

70% SO_2 removal (minimum) to a maximum SO_2 emission of 0.6 lb SO_2/MBtu
0.6 lb SO_2/MBtu maximum emission up to 90% SO_2 removal
90% SO_2 removal (minimum) to a maximum SO_2 emission of 1.2 lb SO_2/MBtu
1.2 lb SO_2/MBtu maximum emission

NO_x

Bituminous coal - 0.6 equivalent lb NO_2/MBtu
Subbituminous coal - 0.5 equivalent lb NO_2/MBtu
Lignite - 0.6 equivalent lb NO_2/MBtu

Particulate

0.03 lb/MBtu

EMISSION CONTROL PROCESS DESIGN

With the exception of some standard designs and frequently used reference processes--most notably the limestone FGD process--detailed design features that will be applicable to all evaluations cannot be specified. The diversities of processes and evaluation objectives and continuing technological advances make such an approach impractical. Most designs must be based on a thorough assessment of the objectives of the study, its relationship to past and possible future studies, and on aspects that enhance the scope and detail of the evaluation.

TABLE B-19. PREMISE COAL EMISSION STANDARDS FOR 1979 NSPS

Coal	Equivalent SO_2 content of coal, lb SO_2/MBtu	Overall equivalent SO_2 removal efficiency, %	Equivalent SO_2 removal required in FGD system, %[a]	Controlled outlet emission, lb SO_2/MBtu
Eastern bit., 5.0% S	8.21	90.0	89.5	0.82
Eastern bit., 3.5% S	5.74	89.6	89.1	0.60
Eastern bit., 2.0% S	3.28	81.7	80.7	0.60
Eastern bit., 0.7% S	1.15	70.0	68.4	0.34
Western bit., 0.7% S	1.22	70.0	64.7	0.36
Western subbit., 0.7% S	1.17	70.0	64.7	0.35
N.D. lignite, 0.9% S	1.73	70.0	64.7	0.52

a. Based on FGD system as the only SO_2 control device and the previously defined sulfur retention in the ash.

The standardized design features and procedures outlined in the following sections are followed to the maximum extent compatible with the objectives of the evaluation since this facilitates more detailed evaluations of significant design and operating features and more meaningful identification of cost elements. In all cases, the design and costing procedures are based on division of costs into definable functional areas so that the role of particular functions in determining costs can be identified.

Generic designs based on current practices and technology are usually preferable for evaluating technologies in which several vendors offer proprietary processes (limestone FGD, spray dryer FGD, and fabric filter baghouses are examples of the early 1980s). This approach allows a general assessment of the technology and of design trends and practices which are less effected by the specific concepts and preferences of individual vendors.

Evaluations of proprietary designs depend on the nature and objectives of the evaluation. Standard design features are used as much as is consistent with the objectives of the evaluation. The vendor's specifications and suggestions are used for all features that represent and define the process while preferences that have no effect on the function of the process are--to different degrees, depending on the nature of the features and the objectives of the evaluation--avoided if they reduce the comparability of the process economics.

Particulate Matter

Fly ash and bottom ash collection, handling, and disposal or utilization are included in the evaluation of other emission control processes when the inclusion is pertinent to the evaluation or is expected to be in related future evaluations. (However, these costs are not included in the FGD costs from the Shawnee FGD computer model.) The standard bottom ash system consists of conventional vee-bottom water-filled hoppers with clinker grinders, a hydraulic conveying system with a combined ejector pump and centrifugal pump system, and a dewatering system one-fourth mile from the boiler.

Normal fly ash control consists of rigid-frame cold-side (after the air heater) electrostatic precipitators (ESPs) for coals with 2% or more sulfur and rigid-frame hot-side ESPs for coals with less than 2% sulfur. Fabric filter baghouses may be used in place of ESPs, particularly hot-side ESPs in low-sulfur coal cases, if this favors the evaluation. Baghouses are used with spray dryer FGD for particulate collection. Normally, economizer and air heater (and reactor for NO_x control, if used) and ash hoppers are included in fly ash costs.

Vacuum conveying systems are used for conveying distances less than 300 feet. Vacuum-pressure systems are used when longer conveying distances are necessary. In this case, the vacuum system is used to convey the solids from the collection hoppers to one or more collection points, from which they are conveyed to storage silos in the pressure system. Normally, the vacuum-pressure system is used when more than 24 collection hoppers are involved. The design of the waste conveying system is based on standard industry practices.

The bottom ash dewatering bins, fly ash silos, and spray dryer waste silos are sized for a 64-hour capacity to allow a 5-day, 2-shift disposal operation. The bins and silos are elevated for direct discharge to trucks. Silos for eastern coal fly ash are provided with moisturizer-mixers to add water to the ash as it is discharged.

Flue Gas Desulfurization

The FGD system consists of two or more trains of absorbers supplied by a common inlet plenum into which the flue gas from the power unit duct system discharges. The plenum allows optimization of the FGD system design by making it independent of the power plant duct configuration. The plenum and all equipment between it and the stack plenum are included in the FGD costs. This is based on the premise that in the absence of the FGD system, the flue gas discharged to the inlet plenum would be discharged directly to the stack plenum.

Unless process requirements dictate otherwise, the absorber trains have a maximum size of 125 MW or 513,000 sft^3/min (60°F), whichever is larger. All systems with capacities of 200 MW or more, or processing 340,000 aft^3/min of flue gas, have two or more absorber trains. Each train is assumed to have an annual availability of 85%. Spare trains are included to provide an excess capacity of at least 25%. (This allows the use of an emergency bypass, as discussed below.) All trains, including the spares, are identical although this results in a spare capacity over 25% in some cases: a 200-MW system would have three 100-MW trains, for example. The 500-MW systems with full scrubbing have four operating trains and one spare train and the 1,000-MW systems have eight operating and two spare trains.

All wet-scrubbing systems that do not include prescrubbers such as venturis are equipped with presaturators to cool the flue gas to the saturation temperature (approximately 127°F). Usually these are modified sections of inlet duct equipped with spray headers to spray the flue gas with absorbent liquid. The absorbers are also equipped with mist eliminators and reheaters as required to produce a stack temperature of 175°F. Booster fans are provided to compensate for the pressure drop in the system. Normally, these are induced-draft (ID) fans in each train downstream from the reheater.

Emergency Bypass--

Because the 1979 NSPS allow emergency bypass around the FGD system under some conditions if spare scrubbing capacity is provided, spare scrubbing trains and bypass of 50% of the gas that would normally be scrubbed are included. An emergency bypass of 50% of the scrubbed gas is assumed to be an economic balance between the higher cost of providing additional bypass and the small likelihood of multiple scrubbing train failures, which would make higher bypass rates necessary. The bypass is installed as two identical ducts from each end of the inlet plenum to the stack plenum downstream from the scrubbing trains. Particulate collection equipment is not bypassed.

Partial Scrubbing--

In some cases, depending on the sulfur content of the coal and SO_2 removal requirements, scrubbing a portion of the flue gas at a high removal efficiency and combining it with the remaining flue gas may be more economical than scrubbing all of the flue gas at a lower removal efficiency. In such cases, the bypassed gas duct requirements and the emergency bypass capability are combined in the same duct. The ducts are sized to handle both the flue gas normally bypassed and emergency bypass of 50% of the flue gas scrubbed. Depending on sulfur content of the coal, for the 500-MW power unit, partial scrubbing could involve scrubbing as little as 375 MW of flue gas. Three operating scrubbing trains and one spare scrubbing train are provided for this case.

Ductwork--

Square ductwork with 2-inch insulation (in standard cases) is used for the inlet plenum and absorber trains. To prevent ash settling, a gas velocity of 50 ft/sec is used for the inlet plenum, all ductwork, and the emergency bypass. A gas velocity of 25 ft/sec is used for the reheater section. Duct material is usually 3/16-inch Cor-Ten steel when the gas temperature is higher than 150°F and 3/16-inch stainless steel when the gas temperature is lower than 150°F.

Removal Efficiencies--

It is assumed that 50% of the SO_3, 95% of the HCl, none of the NO_x, and 50% of the remaining fly ash in the flue gas are removed in the FGD system. For systems requiring a presaturator or humidifier, it is assumed that 5% of the SO_2 is removed in the presaturator and that the remaining SO_2 removal takes place in the FGD absorber.

Mist Eliminator--

The mist eliminator is a fiberglass-chevron-baffle type. The mist eliminator reduces entrained moisture to a maximum level of 0.1% (by weight) of the flue gas. This maximum level is used for calculation of the amount of flue gas reheat required.

Flue Gas Reheat--

A reheater consisting of a steam-heated tube bank is provided in each train to provide a stack temperature of 175°F. This is considered necessary to evaporate corrosive liquid not removed by the mist eliminator and to provide adequate plume buoyancy. The size of the reheater is determined by the temperature of the scrubbed flue gas (which is assumed to be 125°F for wet-scrubbing systems), the quantity of flue gas bypassed, and the heat of compression through the ID booster fans--which are assumed to be equivalent to an adiabatic compression equal to the pressure drop in the FGD system. Necessary information for calculation of the steam requirements and reheater surface area is shown in Table B-20 and a sample calculation is shown in Table B-21.

For full-scrubbing processes, the reheater tubes are Inconel 625 for corrosion resistance below 150°F and the remainder is Cor-Ten steel. In cases in which the scrubbed flue gas is not heated to 175°F (as in the case of partial bypass), the quantity of Inconel tubes remains the same and the quantity of Cor-Ten tubes is reduced.

Piping--

Carbon steel piping is used for water and other noncorrosive and nonabrasive liquids. Stainless steel is used for slurry and other corrosive or abrasive liquid lines 3 inches in diameter or less; neoprene-lined carbon steel is used for larger lines carrying these liquids. For slurry lines, plug valves are used for lines up to 3 inches in diameter; eccentric plug valves are used for 3- to 20-inch lines; and knife gate valves are used for lines larger than 20 inches in diameter. Pneumatic actuators are provided for valves 12 inches in diameter or larger.

Buildings--

Metal buildings are provided when it is necessary to provide weather protection. The buildings have 6-inch concrete floors, insulation, electrical heating, overhead doors, and other features required for their function. Normally, buildings are provided for feed preparation, waste dewatering,

TABLE B-21. SAMPLE REHEATER CALCULATIONS

Gas to Reheater

	lb/hr
CO_2	1,008,000
HCl	21
SO_2	2,850
O_2	319,800
N_2	3,852,000
H_2O (vapor)	444,873
Total gas	5,627,544
H_2O (liquid entrainment)	5,627
Total	5,633,171

Reheater Heat Duty

	lb/hr	x	Cpm(Btu/lb)[b]	=	Btu/hr
CO_2	1,008,000	x	10.8		10,886,400
HCl	21	x	9.5		200
SO_2	2,850	x	7.9		22,515
O_2	319,800	x	11.2		3,581,760
N_2	3,852,000	x	12.5		48,150,000
H_2O (vapor)	444,873	x	22.6		10,054,130
Total					72,695,005
H_2O (liquid entrainment)	5,627	x	1,043.2[b]		5,870,090
Total					78,565,095

Steam Requirement

78,565,095 Btu/hr ÷ 751.9 Btu/lb = 104,489 lb/hr

Reheater Area

78,565,095 Btu/hr ÷ 4 operating reheaters ÷ 20.8 Btu/ft^2-hr-°F ÷ 319°F[a,b] = 2,960 ft^2

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a. Log mean temperature difference (ΔT_L) = $(T_1 - T_2)/(\ln(T_1/T_2))$
   T_1 = Tsteam - Tgas in = 470 - 125 = 345
   T_2 = Tsteam - Tgas out = 470 - 175 = 295
   $\Delta T_L = (345 - 295)/(\ln(345/295))$

b. For a temperature change from 125°F to 175°F only.

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storage, offices, laboratories, and for spray dryer FGD reactors (for temperature control).

TABLE B-20. REHEATER DATA

Compound	C_{pm} (Btu/lb)[a]
CO_2	10.8
HCl	9.5
SO_2	7.9
SO_3	8.2
O_2	11.2
N_2	12.5
NO	12.0
NO_2	10.2
H_2O (vapor)	22.6

Steam:
saturated at 470°F (500 psig), heat of vaporization 751.9 Btu/lb

Reheater overall heat transfer coefficient:
20.8 Btu/ft^2-hr-°F

Entrained water enthalpy:
liquid at T = 125°F: 92.9 Btu/lb
vapor at T = 175°F: 1136.1 Btu/lb
H^a = 1043.2 Btu/lb

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[a] For temperatures between 125°F and 175°F only.

Spare Equipment--

Spare equipment is provided in accordance with general practice. For most processes, the following spares are provided:

- A spare train of crushing and grinding equipment
- Slakers
- Waste filters
- Pumps
- A spare scrubbing train or trains

NO_x Control

Reduction of NO_x emissions to meet the 1979 NSPS is assumed to be met by modifications to the boiler combustion system. Evaluations of NO_x control processes are normally based on an 80% reduction of these emissions.

With the exception of selective catalytic reduction (SCR) processes, NO_x control processes are usually based on proprietary designs. These vary considerably from various forms of combustion modification and furnace injection to--conceivably--wet scrubbing. The designs in these cases are dealt with on an individual basis, usually following the vendor's specification. For processes that control both NO_x and SO_2, the comparative processes are the standard limestone FGD process and a generic SCR process.

A generic SCR process design is based on the designs of U.S. vendors of the process. For the base case conditions, parallel vertical reactors up to 250 MW in size (two reactors for the 500-MW base case) are used. Flue gas is ducted from the outlet of the boiler economizer to the reactors and from the reactors to the boiler air heater. The air heater is modified to accommodate the buildup of ammonia salts and the incremental costs are included in the NO_x control costs. An economizer bypass to maintain the flue gas temperature during low-load operation and an emergency bypass for the reactors are also included. No spare reactor trains are provided. The assumed catalyst life is equivalent to the catalyst life generated by process vendors and the catalyst volume is based on maintenance of the design NO_x reduction over the catalyst life. Boiler operation is assumed to be unaffected by the NO_x control process (e.g., catalyst changes and other maintenance occur during boiler outages).

WASTE PROCESSING AND DISPOSAL

For processes producing a waste, either landfill or pond disposal is provided. Normally, an onsite disposal facility one mile from the process facility is used. The size of the disposal facility is based on the lifetime volume of waste. Both the landfill and pond designs and costs are determined using the landfill and pond models in the Shawnee computer model.

Normally, landfill disposal is used for ash and insoluble FGD waste. Ponds are used for wastes, such as coal-cleaning fines, that are not normally dewatered. Ponds, which serve as solid impoundments, are also used for soluble wastes such as sodium-based FGD waste.

Waste storage facilities are normally based on truck transport and landfill disposal on a 2-shift, 5-day-week schedule. A 64-hour silo and stockpile storage capacity is provided to allow the landfill operating schedule. For pond disposal, which may be used in special studies or for waste that is normally ponded, an 8-hour storage tank is provided. The waste is pumped directly to the pond and the supernate is returned for reuse.

Waste Properties

The densities upon which equipment sizes and storage volumes are based are shown in Table B-22. Settled and compacted moisture contents and bulk densities are also shown for use in disposal site designs, which are discussed below. These are used in conceptual design evaluations in which uniform representative values are more useful than specific values or in which specific data are unavailable. The values in Table B-22 are based on published data and are representative of the rather large range over which the moisture contents and bulk densities of most wastes vary, depending on the conditions under which they were produced. In evaluations based on specific wastes, measured values or more specific estimates should be used.

TABLE B-22. WASTE BULK DENSITIES

	Model defaults bulk density, lb/ft3	
	In-process waste	Compacted
Waste Sludge		
Sulfite (filtered)	70	85
Gypsum (filtered)	75	95
Fixed sulfite (filtered)	90	106
Fixed sulfate (filtered)	85	100
Dry FGD waste	70	85

FGD Waste Processing and Handling

High-sulfite slurry (70% $CaSO_3 \cdot 1/2H_2O$ and 30% $CaSO_4 \cdot 2H_2O$) is normally dewatered and mixed with dry fly ash and lime (100% fly ash and 3.5% lime, both based on the dry weight of FGD solids) for landfill disposal. The slurry from the absorbers is first dewatered to 30% solids in a thickener, then filtered to 55% solids in rotary vacuum filters. The filter cake is mixed with the fly ash and lime in a pug mill and conveyed to a radial-arm stacker that stacks it in a 64-hour capacity stockpile for removal to a landfill.

Gypsum waste (95% $CaSO_4 \cdot H_2O$ or more) is thickened to 30% solids and filtered to 85% solids in rotary vacuum filters. The filter cake is stacked in a 64-hour capacity stockpile by a radial-arm stacker from which it is removed to a landfill.

Waste Transportation

Trucks are used for transportation of solid wastes. Bottom ash and fly ash are discharged directly from the elevated dewatering bins and silos into the trucks. A moisturizer-mixer mounted on the storage silo is used to add water to fly ash from eastern bituminous coal (the quantity of water is based on the optimum compaction moisture) to control dusting. Other fly ash and spray dryer FGD wastes, which are likely to have cementitious properties, are moisturized with similar truck-mounted moisturizers at the disposal site.

Wastes in slurry form are sluiced to the disposal site and the supernate is returned for reuse. If the slurry is abrasive (ash and coal-cleaning waste), an abrasion-resistant ash-sluicing pipe is used. Equipment for control of the return water pH and scaling potential is included in all wet sluicing systems.

Disposal Site

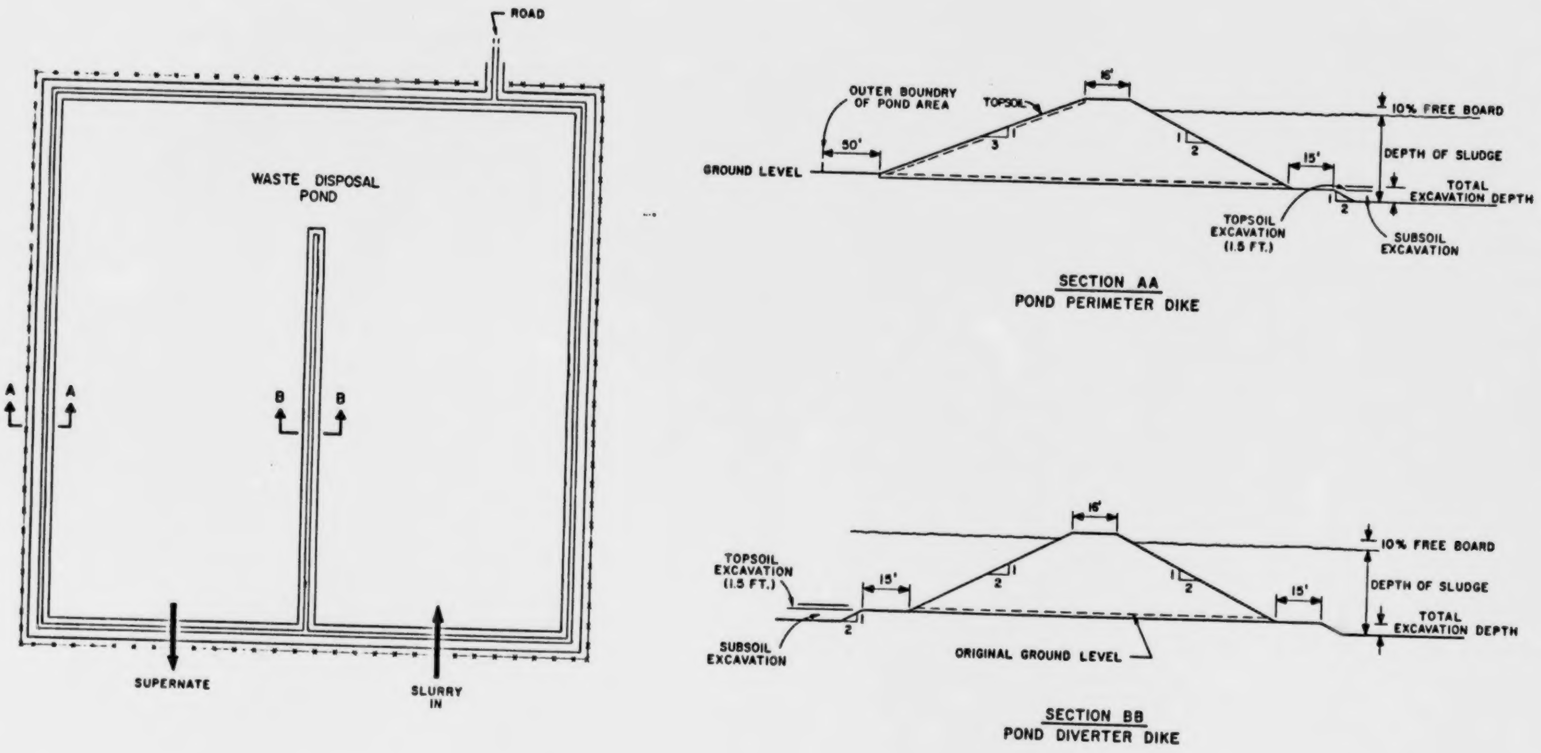
Both the pond and landfill design and costs are determined using the Shawnee FGD computer model, which allows numerous design variations. The standard conditions are described below. The disposal site is normally situated one mile from the process facility. Sufficient land is provided for disposal during the remaining life of the facility. The disposal site is assumed to be an area of low relief with sufficient soil for dike construction or landfill requirements.

Pond--

Disposal ponds are square, earthen-diked enclosures with a medium diverter dike. Dikes are constructed from material removed from the impoundment area as shown in Figure B-4. The entire impoundment area is lined with 12 inches of clay (assumed available onsite). Pond size and depth are normally adjusted to minimize the sum of land and construction costs. Pond costs include a 6-foot security fence around the perimeter dike, security lighting, a topsoil storage area, and one upstream and three downstream groundwater monitoring wells.

Landfill--

The landfill, one mile from the fixation area, has a square configuration with a 20-foot rise and a 6-degree cap, as shown in Figure B-5. After topsoil removal, the landfill area is lined with 12 inches of clay (assumed available onsite) with a drain system to a sump and 24 inches of bottom ash is placed on the liner. Surface runoff drains into a catchment ditch around the perimeter. The ditch drains into a catchment basin for pH adjustment. Land requirements include the landfill, the catchment basin, an office, equipment storage area, topsoil storage area, and a 50-foot perimeter of undisturbed land surrounding the landfill site. Costs for access roads; a 6-foot security fence around the total landfill area; security lighting; and topsoil stripping, replacement, and revegetation are included. One upstream and three downstream groundwater monitoring wells are also included.


ROAD
WASTE DISPOSAL POND
A
A
B
B
SUPERNATE
SLURRY IN
OUTER BOUNDRY OF POND AREA
TOPSOIL
16'
50'
GROUND LEVEL
3
1
1
2
15'
10% FREE BOARD
DEPTH OF SLUDGE
TOTAL EXCAVATION DEPTH
TOPSOIL EXCAVATION (1.5 FT.)
SUBSOIL EXCAVATION
1
2
16'
TOPSOIL EXCAVATION (1.5 FT.)
SUBSOIL EXCAVATION
15'
2
1
2
1
1
2
15'
10% FREE BOARD
DEPTH OF SLUDGE
TOTAL EXCAVATION DEPTH
ORIGINAL GROUND LEVEL

SECTION AA
POND PERIMETER DIKE

SECTION BB
POND DIVERTER DIKE

Figure B-4. Pond design.

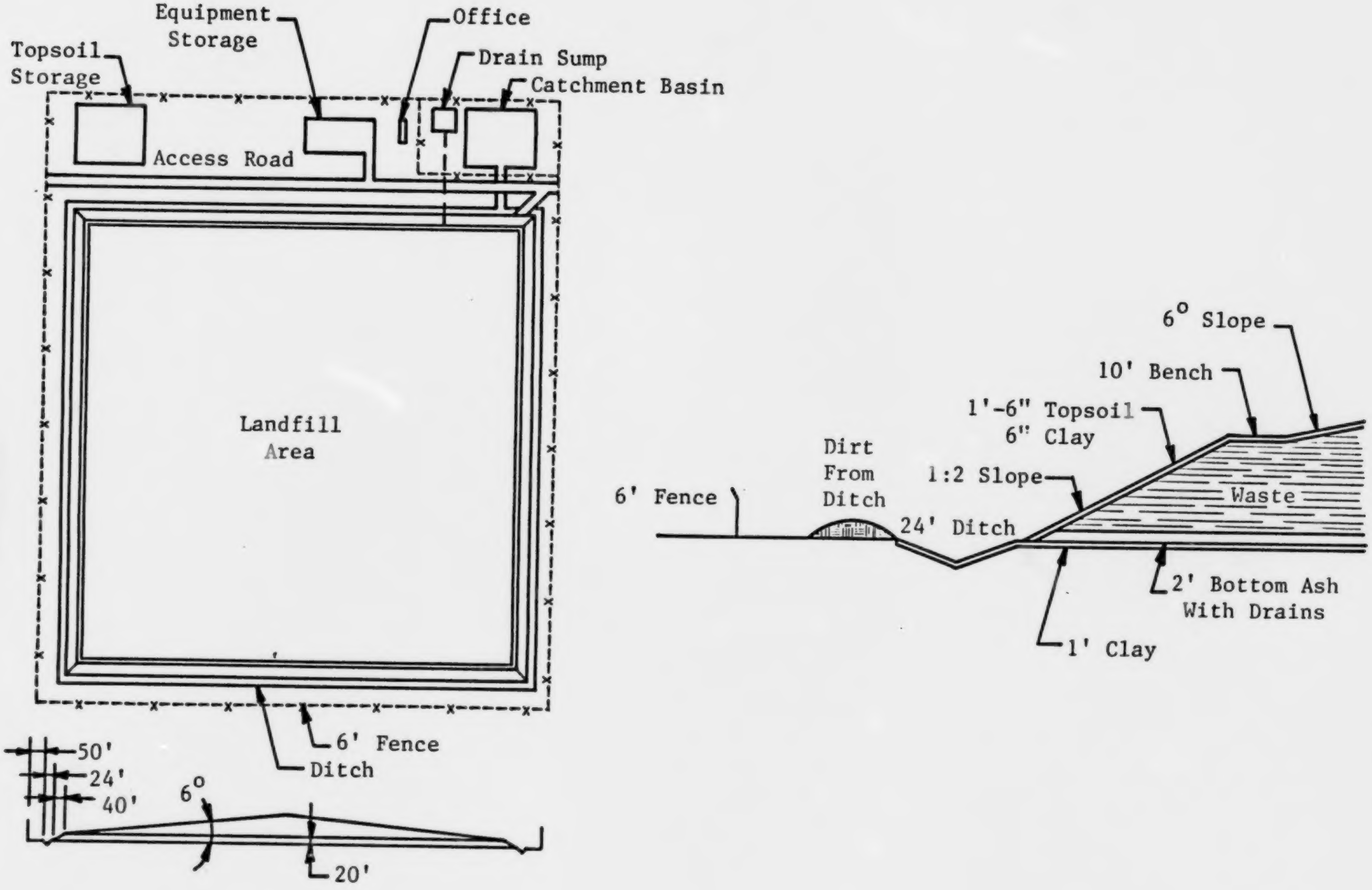

Topsoil Storage
Equipment Storage
Office
Drain Sump
Catchment Basin
Access Road
Landfill Area
6' Fence
Ditch
50'
24'
40'
6°
20'
6° Slope
10' Bench
1'-6" Topsoil
6" Clay
Dirt From Ditch
1:2 Slope
6' Fence
24' Ditch
Waste
2' Bottom Ash With Drains
1' Clay

Figure B-5. Landfill design.

ECONOMIC PREMISES

Schedule and Cost Factors

The construction schedule used as a cost basis is shown in Figure B-6. A 3-year construction period, from early 1984 to late 1986, is used. Mid-1985 costs are used for capital investment. Mid-1987 costs are used for annual revenue requirements. These costs represent the midpoint of construction expenditures and the midpoint of the first year of operation. Costs are projected from Chemical Engineering cost indexes (17), as shown in Table B-23. Frequently used costs are shown in Table B-24.

Capital Cost Estimates

Four grades of capital cost estimates are prepared depending upon the intended use and the amount of information available. The grades, in increasing order of accuracy, are (1) order of magnitude, (2) study, (3) preliminary, and (4) definitive. The two grades normally used are the study and preliminary grades. The purpose, information required, and predicted accuracy are listed in Table B-25.

A typical capital investment sheet is shown in Table B-26. The capital investment sheet is divided into three major sections: direct investment, indirect investment, and other capital investment.

Direct Investment--

Direct investment consists of total process capital; services, utilities, and miscellaneous; and waste disposal investment. Total process capital is determined from the equipment list. Using standard estimating techniques (18,19,20) and the Chemical Engineering cost indexes and projections shown in Table B-23, the equipment cost and installation costs of each area are estimated. The installation costs include charges for all piping, foundations, excavations, structural steel, electrical equipment, instruments, ductwork (all ductwork is included in the gas-handling area), paint, buildings, taxes, freight, and a premium for 7% overtime construction labor as shown in Figure B-7. The total process area costs are summed on the area summary sheet shown in Figure B-8 to give the total process capital.

Service facilities such as maintenance shops, stores, communications, security, offices, and road and railroad facilities are estimated or allocated on the basis of process requirements. Included in the utilities investment are necessary electrical substations, conduit, steam, process water, fire and service water, instrument air, chilled water, inert gas, and compressed air distribution facilities. Services, utilities, and miscellaneous are in the range of 4% to 8% of the total process capital. For most cases, 6% is to be used, higher for processes and lower for waste disposal facilities. The base case limestone-scrubbing process is charged 6% for services, utilities, and miscellaneous.

All equipment and direct construction costs associated with waste disposal are included in waste disposal costs. For ponds, this includes pond

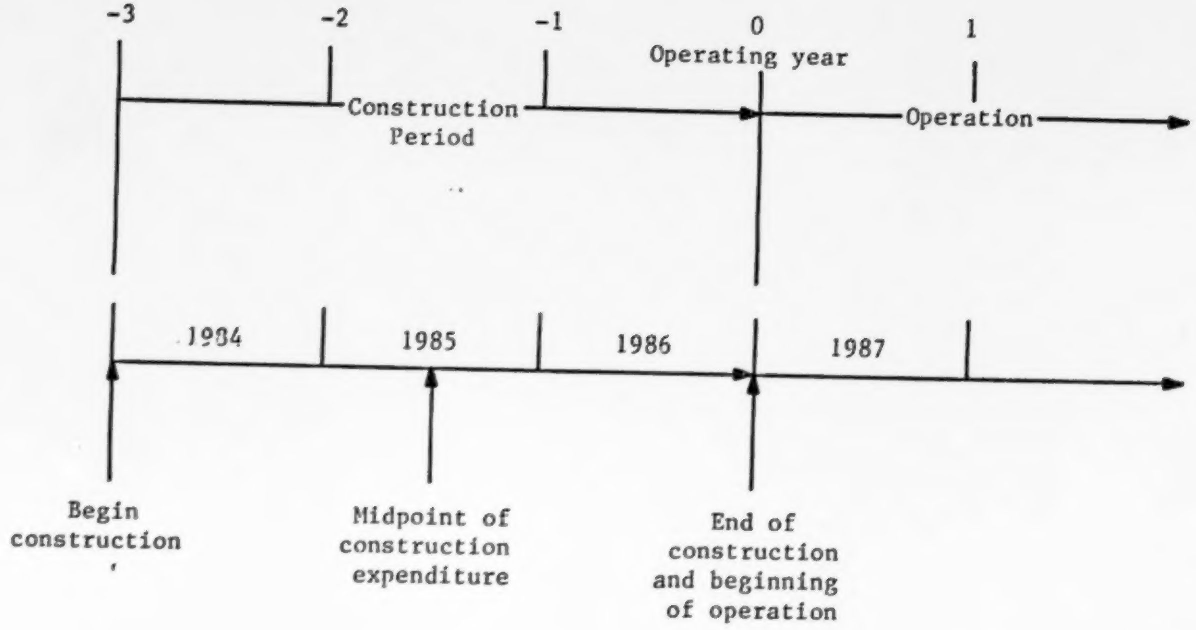

-3
-2
-1
0
1
Operating year
Construction Period
Operation
1984
1985
1986
1987
Begin construction
Midpoint of construction expenditure
End of construction and beginning of operation

Figure B-6. Construction schedule.

TABLE B-23. COST INDEXES AND PROJECTIONS

Year:	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984[a]	1985[a]	1986[a]	1987[a]	1988[a]
Plant	137.2	144.1	165.4	182.4	192.1	204.1	218.8	238.7	261.1	297.0	314.0	316.9	326.4	346.0	366.8	388.8	412.1
Material[b]	135.4	141.9	171.2	194.7	205.8	220.9	240.6	264.4	292.6	323.0	336.2	336.0	346.1	366.8	388.9	412.2	436.9
Labor[c]	152.2	157.9	163.3	168.6	174.2	178.2	185.9	194.9	204.3	242.4	263.9	267.6	275.6	292.2	309.7	328.3	348.0

a. TVA projections.
b. Same as "equipment, machinery, supports," *Chemical Engineering* index.
c. Same as "construction labor," *Chemical Engineering* index.

TABLE B-24. COST ACTORS

1987 Utility Costs

Electricity	\$0.055/kWh
Steam	\$4.00/klb; \$5.30/MBtu
Eastern bit. coal (<1% S)	\$63.00/ton; \$2.30/MBtu
Eastern bit. coal (2% S)	\$53.00/ton; \$2.03/MBtu
Eastern bit. coal (3% S)	\$43.00/ton; \$1.81/MBtu
Eastern bit. coal (4% S)	\$38.00/ton; \$1.71/MBtu
Western bit. coal (0.7% S)	\$65.00/ton; \$3.40/MBtu
Western subbit. coal (0.7% S)	\$35.00/ton; \$2.10/MBtu
N.D. lignite (0.9% S)	\$18.00/ton; \$1.35/MBtu
Fuel oil No. 6	\$10.50/MBtu
Diesel fuel	\$1.60/gal
Natural gas	\$6.00/MBtu
Filtered river water	\$0.16/kgal (up to 0.6 Ggal)
	\$0.14/kgal (0.6-2 Ggal)
	\$0.12/kgal (2-5 Ggal)
	\$0.10/kgal (over 5 Ggal)

1987 Labor Costs

FGD	\$19.00/man-hr
Waste disposal	\$24.00/man-hr
Analysis	\$26.00/man-hr

1987 Raw Material Costs

Limestone	\$15.00/ton (95% $CaCO_3$, dry basis)
Lime	\$90.00/ton (pebble, 95% CaO, dry basis)
Ammonia	\$230.00/ton
Soda ash	\$190.00/ton (99.8% Na_2CO_3)
Adipic acid	\$1,500.00/ton
MgO	\$510.00/ton

1985 Land Cost

\$6,000.00/acre

These cost factors are based on a north-central plant location.

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TABLE B-25. CAPITAL COST ESTIMATE CLASSIFICATION

Grade	Purpose	Minimum information required	Predicted accuracy, +%	Predicted accuracy, -%
Order of magnitude (ratio estimate)	Preliminary feasibility study to determine whether continued investigation is merited. Rough comparison of alternatives.	General design basis,[a] a flowsheet and material balance, heat and energy balance. For the order-of-magnitude estimates, this information is of a tentative nature, developed from a preliminary process concept.	>50	>50
Study (factored estimate)	Comparison of alternatives. Preliminary screening. Preliminary budget preparation. Authorization for funding for an engineering study or for development of additional information.	All of the above on a firm, rather tentative basis plus overall layout of manufacturing and nonmanufacturing facilities, sized equipment and instrument lists, and performance data sheets.	40	20
Preliminary (initial budget or scope estimate)	Preliminary budget approval. More accurate comparison of alternatives. Follow up of an order-of-magnitude or study estimate.	All of the study estimate requirements plus process control diagrams, process piping sketches with sizes, plan and elevation drawings, offsite descriptions, including sizes and capacities.	30	15
Definitive (project control estimate)	Final capital authorization. Project cost control. Follow up on order-of-magnitude, study, or preliminary estimates for more accurate information. Generally reserved for a real construction project with a known site.	All of the preliminary estimate requirements plus piping plan and elevation drawings integrated with the equipment plan and elevation drawings, electrical layout single line drawings, detailed piping and instrumentation flowsheets, layout of nonmanufacturing facilities, design sketches for unusual equipment items, and specific site data, including utilities and transportation availability, soil bearing, wind and snow loads.	20	10

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a. General design basis includes product, product specifications, plant capacity, storage requirements, operating stream time, provisions for expansion, and raw materials and their storage requirements.

TABLE B-26. CAPITAL INVESTMENT SHEET

TABLE LIME SPRAY DRYER CAPITAL INVESTMENT

(500-MW new coal-fired power unit; 3.5% S in coal;
89% SO_2 removal; onsite solids disposal)

Direct Investment	Investment, k$
Materials handling	
Feed preparation	
Gas handling	
SO_2 absorption	
Particulate removal	
Spray dryer solids handling	
Baghouse solids recycle	
Total process capital	
Services, utilities, and miscellaneous	
Total direct investment excluding landfill	
Solids disposal equipment	
Landfill construction	
Total direct investment	
Indirect Investment	
Engineering design and supervision	
Architect and engineering contractor	
Construction expense	
Contractor fees	
Contingency	
Disposal area indirects	
Total fixed investment	
Other Capital Investment	
Allowance for startup and modifications	
Interest during construction	
Royalties	
Land	
Working capital	
Total capital investment	
Dollars of total capital per kW of generating capacity	

Basis: North-central plant location represents project beginning early 1984, ending late 1986; average cost basis for scaling, mid-1985.
One spare scrubber train, 50% emergency bypass, spare pumps.
Landfill located one mile from power plant.
FGD process costs begin with feed plenum. Stack plenum and stack excluded.

Area	% of process equipment	Material	Labor[a]	Total
Process equipment	X			
Piping & insulation				
Concrete foundations				
Excavations, site preparation, roads, etc.				
Structural				
Electrical				
Instrumentation				
Ducts, chutes, expansion joints, etc.				
Paint & miscellaneous				
Buildings				
Trucks & earthmoving equipment				
Subtotal				
Freight (3.5% of process material)			X	
Tax (4% of material subtotal)			X	
Total process area cost				

a. Includes premium for 7% overtime, i.e., labor is 0.93 (straight time labor) + (0.07)(1.5)(straight time labor) or 1.035 (straight time labor).

Figure B-7. Process area cost summary sheet.

Area	Description	Total process area cost, $	Total process capital, $
1	Materials handling		
2	Feed preparation		
3	Gas handling		
4	SO_2 absorption		
5	Particulate removal		
6	Spray dryer solids handling		
7	Baghouse solids recycle		

Figure B-8. Area summary sheet.

construction costs from the pond computer model. For landfills, mobile equipment and construction costs are included. All mobile equipment involved in loading and transporting the waste from the in-process storage area, as well as working the landfill, is included in solids disposal equipment. The landfill construction cost, as calculated from the landfill computer model, is listed separately from the solids disposal equipment. The sum of total process capital; services, utilities, and miscellaneous; and the waste disposal cost is the total direct investment.

Indirect Investment--

Indirect capital investment covers fees for engineering design and supervision, architect and engineering contractor, construction expense, contractor fees, and contingency. Listed in Table B-27 are the ranges to be used to calculate the process and waste disposal indirect investments. The base percentages are normally used. The low and high ranges are used if the process being studied is either much more complex than the typical system (the higher percentage factors are used) or much less complex (the lower percentage factors are used). The limestone- and lime-scrubbing processes use the low percentages for a 1,000-MW unit, base percentages for a 500-MW unit, and the high percentages for a 200-MW unit. Contingency is included to compensate for unforeseen expenses. The contingency varies depending on the process and the waste disposal method, as shown in Table B-28. The limestone- and lime-scrubbing processes are assessed a contingency of 10% for the process and 20% for the landfill.

Other Capital Investment--

The allowance for startup and modifications is applied as a percentage of the total fixed investment. Since the startup and modification costs for the waste disposal area are assumed to be negligible, this allowance is calculated as a percentage of the total process fixed investment only. The values used are shown in Table B-29. The limestone- and lime-scrubbing processes are assessed at a rate of 8% for this charge.

The cost of borrowed funds (interest) during construction is 15.6% of the total fixed investment (both process and waste disposal). This factor is based on an assumed 3-year construction schedule and is calculated with a 10% weighted cost of capital with 25% of the construction expenditures in the first year, 50% in the second year, and 25% in the third year of the project construction schedule. Expenditures in a given year are assumed uniform over that year. Startup costs are assumed to occur late enough in the project schedule that there are no charges for the use of money to pay startup costs. Table B-30 illustrates the calculation of the interest during construction for 3- through 6-year construction schedules.

Most processes will include a one-time royalty charge using either an actual royalty obtained from the vendor or 1% of the total process capital involved. Processes exempt from royalties due to their generic design are limestone and lime processes, including those with forced oxidation or adipic acid or both, and the magnesia process.

TABLE B-27. RANGE OF INDIRECT INVESTMENTS

Indirect Investment, Process

	% of total direct investment excluding waste disposal investment		
	Low	Base	High
Engineering design and supervision	6	7	8
Architect and engineering contractor	1	2	3
Construction expense	14	16	18
Contractor fees	4	5	6
Total	25	30	35

Waste Disposal Indirects FGD Pond, FGD Landfill, or Ash Pond

	% of total direct waste disposal investment[a]		
	Low	Base	High
Engineering design and supervision	2	2	2
Architect and engineering contractor	1	1	1
Construction expense	7	8	9
Contractor fees	4	5	6
Total	14	16	18

Ash Landfill

	% of total direct waste disposal investment[a]
	Base
Engineering design and supervision	6
Architect and engineering contractor	3
Construction expense	10
Contractor fees	6
Total	25

a. Pond (or landfill) construction only.

TABLE B-28. CONTINGENCY

Process Contingency	
	% of total direct investment excluding waste disposal plus process indirect investment
Limestone and lime slurry	10
Limestone and lime - forced oxidation	10
Limestone and lime - forced oxidation with adipic acid	10
All others	20
Waste Disposal Contingency	
	% of total waste disposal direct investment plus waste disposal indirect investment
FGD pond	10
Ash pond	10
FGD landfill	20
Ash landfill	10

TABLE B-29. ALLOWANCE FOR STARTUP AND MODIFICATIONS

Process	
	% of total fixed investment for process only
Limestone and lime (generic)	8
All other processes	10
Waste Disposal	
	% of total fixed investment for waste disposal only
Ponds and landfills	0

TABLE B-30. INTEREST DURING CONSTRUCTION ILLUSTRATION

Three-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
3-2	1.2686	x	0.250	=	0.317
2-1	1.1533	x	0.500	=	0.577
1-0	1.0484	x	0.250	=	0.262

Total fixed investment plus interest during construction: 1.156

Interest during construction = 1.156 - 1.000 = 0.156 or 15.6%

Four-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
4-3	1.3955	x	0.150	=	0.209
3-2	1.2686	x	0.300	=	0.381
2-1	1.1533	x	0.350	=	0.404
1-0	1.0484	x	0.200	=	0.210

Total fixed investment plus interest during construction: 1.204

Interest during construction = 1.204 - 1.000 = 0.204 or 20.4%

Five-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
5-4	1.5349	x	0.10	=	0.154
4-3	1.3955	x	0.20	=	0.279
3-2	1.2686	x	0.30	=	0.381
2-1	1.1533	x	0.25	=	0.288
1-0	1.0484	x	0.15	=	0.157

Total fixed investment plus interest during construction: 1.259

Interest during construction = 1.259 - 1.000 = 0.259 or 25.9%

(Continued)

TABLE B-30. (Continued)

Six-Year Construction Schedule

Years from startup	Compound amount factor[a]		Fraction of total plant investment		
6-5	1.6886	x	0.10	=	0.169
5-4	1.5349	x	0.15	=	0.230
4-3	1.3955	x	0.25	=	0.349
3-2	1.2686	x	0.25	=	0.317
2-1	1.1533	x	0.15	=	0.173
1-0	1.0484	x	0.10	=	0.105

Total fixed investment plus interest during construction: 1.343

Interest during construction = 1.343 - 1.000 = 0.343 or 34.3%

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[a] Present worth and compound amount factor using the 10% cost of capital with continuous compounding (18).

Years from startup	Uniform expenditure present worth (18)	Compound amount factor (18)
7-6	0.5384	1.8574
6-5	0.5922	1.6886
5-4	0.6515	1.5349
4-3	0.7166	1.3955
3-2	0.7883	1.2686
2-1	0.8671	1.1533
1-0	0.9538	1.0484

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Land--

All land associated with the process and waste disposal area is charged to the process. The cost of land is $6,000 per acre.

Working Capital--

Working capital is the total amount of money invested in raw materials, supplies, finished products, accounts receivable, and money on deposit for payment of operating expenses. For these premises, working capital is defined as the equivalent cost of 1 month's raw material cost, 1.5 months' conversion cost, 1.5 months' plant and administrative overhead costs (all of the above are found on the annual revenue requirements sheet), and 3% of the total direct capital investment (from the capital investment sheet). One month is defined as 1/12 of annual costs. The equation is shown below:

$$\begin{aligned}\text{Working capital} = {} & 1/12\ (\text{total raw materials cost}) + \\ & (1.5)\ (1/12)\ (\text{total conversion cost}) + \\ & (1.5)\ (1/12)\ (\text{plant and administrative overhead}) + \\ & 0.03\ (\text{total direct investment})\end{aligned}$$

Battery Limits--

Since battery limits costs typically include most of the associated indirect investments, battery limits costs have their own indirect investment factors as shown below:

	% of battery limits cost
Engineering design and supervision	6
Architect and engineering contractor	1
Construction expense	14
Contractor fees	0
Contingency	10

Retrofit Factor--

For existing plant cases, a retrofit factor is assigned to cover the additional investment required. Each of the area investments (i.e., material handling, etc.) is multiplied by the retrofit factor. Retrofit factors vary widely depending on the process and the site involved (21). For emission control processes which are coupled to the boiler, the following retrofit factors are used:

Process	Retrofit factor	Reason
Limestone scrubbing	1.3	These scrubbing systems are add-on in that they require no boiler modifications. This factor for the retrofit cases is due to the need to fit the equipment into available space.
Spray dryer	1.5	These scrubbing systems require relatively minor modifications to the boiler and ductwork. This factor also includes the expense of fitting the equipment into the available space.
NO_x flue gas treatment (SCR)	1.7	These control systems require extensive modifications to the boiler economizers and air heaters and the associated ductwork. This factor also includes the expense of locating the equipment in the available space.

It is assumed that most FGD systems will be of the add-on type and, therefore, use the 1.3 retrofit factor.

Annual Revenue Requirements

Annual revenue requirements consist of various direct and indirect operating and maintenance costs and capital charges. Annual revenue requirements normally vary from year to year as operating and maintenance costs change and capital charges decline. Thus, no single year is necessarily representative of the lifetime costs, nor can single-year undistorted comparisons be made among processes with different ratios of operating costs to capital charges. In addition, it is necessary to take into account the effect of time on the value of money (for inflation, the future earning power of money spent, and other factors).

Frequently these factors are accounted for by levelizing (22). Levelization converts all the varying annual revenue requirements to a constant annual value, such that the sum of the present worths of the levelized annual revenue requirements equals the sum of the present worths of the actual annual revenue requirements. The levelized value is calculated by multiplying the revenue requirements for each year by the appropriate present worth factor and summing the present worth values. Then the single present worth value is converted to equal annual values by multiplying the result by the capital recovery factor.

In these premises, the operating and maintenance costs are levelized by multiplying the first-year operating and maintenance cost by a levelizing factor. The levelized capital charges are determined by levelizing the percentage of capital investment applied yearly as capital charges. The levelizing factor includes a discount factor reflecting the time value of money and an inflation factor reflecting the effects of inflation during the operating life of the system. The discount rate used is 10% and the inflation rate used is 6%. The levelizing factor produced varies with the remaining life of the system. Calculation of the levelizing factor for operating and maintenance costs and of levelized capital charges is discussed below.

A typical annual revenue requirement tabulation is shown in Table B-31. Direct costs consist of raw material and conversion costs. These, combined with overheads, are the operating and maintenance costs. For processes that produce a salable byproduct, byproduct sales are applied as a credit to the operating and maintenance costs. Levelized capital charges are calculated as a percentage of the capital investment and added to the operating and maintenance costs to provide the first-year annual revenue requirements. The levelized annual revenue requirements are determined by multiplying the operating and maintenance costs by the levelizing factor and adding the product to the same levelized capital charges used in the first-year annual revenue requirements.

Operating and Maintenance Costs--

Frequently used raw material costs and standard conversion costs are shown previously in Table B-24. Other costs are obtained from vendors or published information. These costs are converted to 1987 costs using the cost indexes in Table B-23 or industry projections.

Raw materials--Consumables required for their chemical or physical properties, other than fuel for the production of heat, are classified as raw materials. Raw material costs are determined as necessary from vendor quotations or published sources and escalated to 1987 costs. All costs are delivered costs.

Operating labor and supervision--Unit labor costs for 1987 were shown in Table B-24. The allocation of operating labor and supervision depends on the process complexity, number of process areas, labor intensity of the process, and operating experience.

Utilities--Services used, such as steam, electricity, process water, fuel oil, and heat credits, are charged under the utilities heading. Unit 1987 costs are shown in Table B-24. Costs for steam and electricity are based on the assumption that the required energy is purchased from another source. This simplifying assumption eliminates the need to derate the utility plant. Process water requirements are defined as any water used by the process being evaluated and are usually determined by the material balance. Steam requirements are for flue gas reheat and process requirements. Electrical power requirements are determined from the installed horsepower of operating electrical equipment (excluding the horsepower of spare equipment). Each motor in operation is assumed to be operating at rated capacity, although this results in higher power consumptions than would actually occur. Electrical requirements are obtained from the equipment list, where the motor horsepower is identified, plus an additional amount for functions such as lighting. A sample calculation is shown in Table B-32.

TABLE B-31. ANNUAL REVENUE REQUIREMENTS SHEET

TABLE LIME SPRAY DRYER PROCESS ANNUAL REVENUE REQUIREMENTS

(500-MW new coal-fired power unit, 3.5% S in coal;
89% SO_2 removal; onsite solids disposal)

	Annual quantity	Unit cost, $	Total annual cost, k$
Direct Costs - First Year			
Raw materials			
Lime	tons	/ton	
Total raw material cost			
Conversion costs			
Operating labor and supervision			
FGD	man-hr	/man-hr	
Landfill disposal	man-hr	/man-hr	
Utilities			
Process water	kgal	/kgal	
Electricity	kWh	/kWh	
Steam	klb	/klb	
Maintenance			
Labor and material			
Analysis	man-hr	/man-hr	
Total conversion costs			
Total direct costs			
Indirect Costs - First Year			
Overheads			
Plant and administrative			
Total first-year operating and maintenance costs			
Levelized capital charges (% of total capital investment)			
Total first-year annual revenue requirements			
Levelized first-year operating and maintenance costs (first-year O and M)			
Levelized capital charges (% of total capital investment)			
Levelized annual revenue requirements			

	M$	Mills/kWh
First-year annual revenue requirements		
Levelized annual revenue requirements		

Basis: One-year, 5,500-hour operation of the system described in the capital investment sheet; 1987 cost basis.

TABLE B-32. SAMPLE ELECTRICAL REQUIREMENT CALCULATION

Electricity requirements are determined by summing the horsepower of all operating electrical equipment and multiplying by a factor of 0.7457 kW/hp. It is assumed that the instantaneous load factor and the power load factor are equal and thus cancel. Additional electricity is added for functions such as lighting. For the limestone and lime processes, 100 kW is added. For other processes, more or less electricity, depending on the process type, size, and complexity, may be necessary.

Sample Calculation

Area	Total operating hp
Materials handling	70.5
Feed preparation	797.5
Gas handling	3,580.0
SO_2 absorption	6,189.0
Stack gas reheat	0.0
Oxidation	4,903.0
Solids disposal	71.0
Total	15,611.0

15,611 hp x 0.7457 kW/hP = 11,641 kW

Miscellaneous (lighting, etc.) + 100 kW

11,741 kW

11,741 kW x 5,500 hr = 64,575,500 kWh

Maintenance--Process maintenance costs are 3% to 10% of the total direct process capital investment depending on process complexity, process equipment, materials handled, process areas, and unit size. The percentages shown in Table B-33 are used under most circumstances. For specific FGD processes, the maintenance percentages shown in Table B-34 are used. For example, a 500-MW limestone-scrubbing process normally has a maintenance factor of 8%.

Waste disposal maintenance costs are estimated from the appropriate model and are typically 3% of the waste disposal site construction costs. Maintenance costs for waste disposal are not shown separately. If no other information is available, the maintenance material-to-labor ratio can be assumed to be 60:40.

TABLE B-33. MAINTENANCE FACTORS

Process conditions	% of total direct investment excluding waste disposal Low	 Base	 High
Corrosive or abrasive slurry	6	8	10
Solids, high pressure, or high temperature	4	5	6
Liquids and gases	3	4	5

TABLE B-34. MAINTENANCE FACTORS FOR SPECIFIC FGD PROCESSES

	Maintenance, % of total direct investment			
	FGD system			
	200 MW	500 MW	1,000 MW	Waste disposal
Limestone and lime (generic)	9	8	7	3
Double alkali	7	6	5	3
Wellman-Lord	7	6	5	-
Magnesia	8	7	6	-
Lime spray dryer (including baghouse)	7	6	5	3

Analysis--Analysis costs are based on process complexity and are listed as a single entry.

Plant and Administrative Overheads--Plant and administrative overheads include plant services such as safety, cafeteria, and medical facilities; plant protection and personnel; general engineering (excluding maintenance), interplant communications and transportation; and the expenses connected with management activities. Plant and administrative overheads for the FGD process are 60% of the total conversion costs less utilities.

Marketing Overhead--This is calculated as 10% of byproduct sales income.

Byproduct Credit--Total revenue from the sale of byproducts is applied as a credit to processes in which a byproduct is salable.

Capital Charges--

Capital charges are those costs incurred by construction of the facility that must be recovered during its life. They consist of returns on equity and debt (discount rate), depreciation, income taxes, and other costs such as insurance and local taxes. In keeping with common practice for investor-owned utilities, the weighted cost of capital is used as the discount rate. Depreciation is stated as a sinking fund factor to simplify calculations. An allowance for interim replacement is included to compensate for possible early retirement of the facility. Credits are also included for tax preference allowances. The capital charges are shown in Table B-35. In keeping with standard practice, book, tax, and economic lives are used in the following calculations. In these premises, however, all three are assumed to be equal.

TABLE B-35. LEVELIZED ANNUAL CAPITAL CHARGES

	Levelized annual capital charge as % of total capital investment			
Remaining life, years	15	20	25	30
Weighted cost of capital	10.00	10.00	10.00	10.00
Depreciation (sinking fund factor)	3.15	1.75	1.02	0.61
Annual interim replacement	0.72	0.67	0.62	0.56
Levelized accelerated tax depreciation	(1.44)	(1.43)	(1.40)	(1.36)
Levelized investment tax credit	(2.39)	(2.14)	(2.00)	(1.93)
Levelized income tax	3.96	4.08	4.20	4.31
Insurance and property taxes	2.50	2.50	2.50	2.50
Levelized annual capital charge	16.5[a]	15.4[a]	14.9[a]	14.7[a]

a. Rounded to three significant figures.

The capital structure is assumed to be 35% common stock, 15% preferred stock, and 50% long-term debt. The cost of capital is assumed to be 11.4% for common stock, 10.0% for preferred stock, and 9.0% for long-term debt. The weighted cost of capital (WCC) is 10.0%. The discount rate (r) is equal to the weighted cost of capital.

Other economic factors used in financial calculations are a 10% investment tax credit rate, 50% State plus Federal income taxes, 2.5% property tax and insurance, and an annual inflation rate of 6%. Salvage value is assumed to be less than 10% and equal to removal cost.

Weighted cost of capital is calculated as follows:

WCC = (fraction long-term debt) (long-term debt cost, %) +
(fraction preferred stock) (preferred stock cost, %) +
(fraction common stock) (common stock cost, %)

The sinking fund factor method of depreciation is used since it is equivalent to straight-line depreciation levelized for the economic life of the facility using the weighted cost of capital. The use of the sinking fund factor does not suggest that regulated utilities commonly use sinking fund depreciation. All factors and rates are expressed as decimals. The equation is:

$$SFF = (WCC)/((1 + WCC)^{N_e} - 1)$$

where: SFF = sinking fund factor
WCC = weighted cost of capital
N_e = economic life in years

An annual interim replacement (retirement dispersion) allowance of 0.56% for new plants and 0.67% for existing plants is also included as an adjustment to the depreciation account to ensure that the initial investment will be recovered within the actual rather than the forecasted life of the facility. Since power plant retirements occur at different ages, an average service life is estimated. The type S-1 Iowa State (23) retirement dispersion pattern is used. The S-1 pattern is symmetrical with respect to the average life axis and the retirements are represented to occur at a low rate over many years. The interim replacement allowance covers replacement of individual items of equipment with typical lifespans less than the life of the power plant. Repair of other equipment is covered by the maintenance charge.

Tax preference allowances are incentives designed to encourage investment as a stimulus to the overall economy. The basic accounting method used is the flow-through method which passes the tax advantage to revenue requirements as soon as they occur.

Using the sum of the years digits method, which allocates costs early in the life of the facility, the accelerated tax depreciation (ATD) is calculated as follows:

$$ATD = (2)(CRF_e)(N_t - (1/CRF_t))/(N_t)(N_t + 1)(WCC)$$

where: CRF_e = capital recovery factor (WCC + SFF) for the economic life
CRF_t = capital recovery factor (WCC + SFF) for the tax life
N_t = tax life in years

Levelized accelerated tax depreciation is calculated as follows:

LATD = (ATD - SLD)(ITR)/(1 - ITR)
where: SLD = straight-line depreciation
= $1/N_b$
N_b = book life in years
ITR = income tax rate

The levelized investment tax credit is calculated as follows:

LITC = (CRF_e)(investment tax credit rate)/(1 + WCC)(1 - ITR)

The levelized income tax is calculated as follows:

LIT = (CRF_b + AIR - SLD)(1 - ((debt ratio x debt cost)/WCC))
(ITR)/(1 - ITR)
where: LIT = levelized income tax
CRF_b = capital recovery factor (WCC + SFF) for the book life
AIR = annual interim replacement

The capital charges are applied as a percentage of the total capital investment, including land and working capital. Although land and most of working capital cannot be depreciated and are not subject to investment tax credit, their inclusion has an insignificant effect on capital charges.

Levelized Operating and Maintenance Costs--
Assuming a constant inflation rate, the levelized operating and maintenance costs are determined by multiplying the first-year operating and maintenance costs by an appropriate levelizing factor, L_f. The levelizing factor is calculated as follows:

L_f = CRF_e ($K + K^2 +$ K3 + --- + K^N)
= CRF_e ($K(1 - K^N))/(1 - K)$
where: CRF_e = capital recovery factor (WCC + SFF) for the economic life (see the discussion of capital charges)
K = (1 + i)/(1 + r); present worth of an inflationary value
i = inflation rate, decimal fraction
r = discount rate, decimal fraction
N_b = book life, years

An inflation rate of 6% (i = 0.06) and a discount rate of 10% (r = 0.10) are used for new units. Values of L_f for power units with a remaining life of

15, 20, 25, and 30 (new unit) years are shown in Table B-36. The first-year operating and maintenance costs are multiplied by the appropriate L_f to obtain the levelized operating and maintenance costs.

TABLE 36. LEVELIZING FACTORS

Book life, N_b	$K = \frac{1 + i}{1 + r}$	$\frac{K(1 - K^{N_b})}{1 - K}$	CRF$_b$ (r, N_b)^b	Levelizing factor, L_f
15	0.96364	11.2965	0.13147	1.485
20	0.96364	13.8669	0.11746	1.629
25	0.96364	16.0028	0.11017	1.763
30^c	0.96364	17.7775	0.10608	1.886

a. Same as economic life (N_e) and tax life (N_t).
b. Discount rate (r) of 10%.
c. New units.

SI SYSTEM NOTATION

The SI system of metric units is not used as the primary numerical system in these premises because of the widespread use of traditional units in correlative and supportive literature and general practice. Use of the SI system is not standardized in the utility industry, although steps in this direction are being made (24). The SI system specifies a number of rules of usage, form, and style in addition to the numerical standards. These too are part of the SI system and should be followed when using it. Detailed procedures for use of SI conventions in the primary data or conversion to SI convention are readily available in the literature. A detailed general guide to SI convention is available in ASTM E 380 79 (25). To provide uniformity in the comparison of data developed from these premises, such a guide should be consulted in using the SI system.

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Appendix C

DETAILED DESCRIPTIONS OF MODEL INPUT VARIABLES

TABLE C-1. MODEL INPUTS - FORTRAN VARIABLE NAMES

Line	
1	CASEID
2	IPRT(1) IPRT(11) IPRT(12) IPRT(13) IPRT(14) IPRT(15) IPRT(16)
3	IPRT(2) IPRT(21) IPRT(22) IPRT(3)
4	IPRT(4) IPRT(41) IPRT(42) IPRT(43) IPRT(44) IPRT(45) IPRT(46) IPRT(47)
5	IPRT(5) IPRT(6) IPRT(7) IPRT(8)
6	MW BHR HVC EXSAIR AIRINL PRES SULO ASHO THG TWG ICOMP
7A	WPC WPCL WPSUL WPH WPO WPN WPH2O WPASH
7B	CO2 HCL SO2 O2 N2 H2O SCFM(1) WASH
8	IBYPAS REHEAT IXSO2 AXSO2 IREM REMSO2
9	NOPSD NSPSD SO4SPL PARSPL SO3OX TAPSAT SDRES SDPRES
10	WPCAO WPINER WPH2OL WPMGOL SLKEFF
11	ICASTO CAOSTO NSPREP IBALML XLMPCT RCYPCT
12	IPART NTBAGH BHPRES BAGRAT BGCOST AC BAGCOM
13	UC(K),K=2,9 II TPI(N),N=1,II
14	INVYR IREVYR IOPSCH IYROP ICLEV IDCAL ONCAP
15	ENGIN ARCTEC FLDEXP FEES CONT START CONINT XINT PCTMNT
16	SENGIN SARCH SFLDEX SFEES SCONT SSTART PDMNTP SDCAP
17	XINFLA PCTOVR FACLEV UNDCAP PCTINS ITAXFR TXRAT FRRAT SERVRT ROYAL
18	ACRE$ DISTLF ILINER XLINA XLINB

(Continued)

TABLE C-1. (Continued)

Line	
19	IOTIME OTRATE RETRO CNDXM CNDXL CNDXP
20	IA(1) - IA(10)
21	IA(11) - IA(20)
22	IA(21) - IA(30)
23	IA(31) - IA(40)
24	IA(41) - IA(50)
25	END OR NEXT

Note: Lines 20-24 are needed only if IOPSCH = 4. The number of entries required on lines 20-24 depends on the number of years specified with the IYROP variable on line 14. Although 30 years is normally used as a maximum plant life, up to 50 years is allowed.

TABLE C-2. MODEL INPUT VARIABLE DEFINITIONS

Line	Variable	Definition	Unit or value
1	CASEID	Case title and identification	alphanumeric characters
2	IPRT(1)	Option to control the printing of input data variables. If a value of zero is selected, no input data variables are printed; the options to individually control the printing of the input variables are ignored.	0 = no print 1 = print
2	IPRT(11)	Controls the printing of boiler characteristics input variables.	0 = no print 1 = print
2	IPRT(12)	Controls the printing of alkali input variables.	0 = no print 1 = print
2	IPRT(13)	Controls the printing of baghouse characteristics input variables.	0 = no print 1 = print
2	IPRT(14)	Controls the printing of scrubber design input variables.	0 = no print 1 = print
2	IPRT(15)	Controls the printing of the landfill waste disposal input variables.	0 = no print 1 = print
2	IPRT(16)	Controls the printing of the economic premises input variables.	0 = no print 1 = print
3	IPRT(2)	Option to control the printing of output data variables. If a value of zero is selected, no output data variables are printed; the options to individually control the printing of the output variables are ignored.	0 = no print 1 = print
3	IPRT(21)	Controls the printing of the combustion related material balance.	0 = no print 1 = print
3	IPRT(22)	Controls the printing of the dry FGD related material balance.	0 = no print 1 = print
3	IPRT(3)	Controls the printing of the landfill equipment list output.	0 = no print 1 = print

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
4	IPRT(4)	Option to control the printing of equipment list output. If a value of zero is selected, no equipment list outputs are printed; if a value of one is selected, all equipment list outputs are printed; options to individually control the printing of the equipment lists output are ignored when a value of zero or one is specified; if a value of two is selected, equipment list output for the area individually specified is printed.	0 = no print 1 = print all 2 = print individual areas as specified
4	IPRT(41)	Controls the printing of the material-handling area equipment list.	0 = no print 1 = print
4	IPRT(42)	Controls the printing of the feed preparation area equipment list.	0 = no print 1 = print
4	IPRT(43)	Controls the printing of the gas-handling area equipment list.	0 = no print 1 = print
4	IPRT(44)	Controls the printing of the SO_2 absorption area equipment list.	0 = no print 1 = print
4	IPRT(45)	Controls the printing of the particulate removal area equipment list.	0 = no print 1 = print
4	IPRT(46)	Controls the printing of the spray dryer solids-handling area equipment list.	0 = no print 1 = print
4	IPRT(47)	Controls the printing of the baghouse solids recycle area equipment list.	0 = no print 1 = print
5	IPRT(5)	Controls the printing of the landfill design dimensions.	0 = no print 1 = print
5	IPRT(6)	Controls the printing of the landfill investment economic output.	0 = no print 1 = print
5	IPRT(7)	Controls the printing of the short-form investment output.	0 = short print 1 = long print

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
5	IPRT(8)	Controls the printing of the short-form revenue output.	0 = short print 1 = long print
6	MW	Gross electric power output	megawatts
6	BHR	Boiler heat rate	Btu/kWh
6	HVC	Heating value of coal	Btu/lb
6	EXSAIR	Excess air	%
6	AIRINL	Air inleakage at the air heater	%
6	PRES	Scrubber pressure	psia
6	SULO	Sulfur to overhead as SO_2 gas (remainder goes to bottom ash)	wt %
6	ASHO	Ash to overhead as particulates (remainder goes to bottom ash)	wt %
6	THG	Temperature of hot gas from economizer	°F
6	TWG	Temperature of gas to spray dryer	°F
6	ICOMP	Composition flag	0 = coal composition 1 = gas composition
7A	WPC	}--Amount of component (C, Cl, S, H, O, N, H_2O, ash) in coal. WPSUL is the total of both organic sulfur and pyritic sulfur.	wt %
7A	WPCL	}	
7A	WPSUL	}	
7A	WPH	}	
7A	WPO	}	
7A	WPN	}	

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
7A	WPH20	}	
7A	WPASH	}	
7B	C02	}--Mol fraction of component (CO_2, HCl, SO_2, O_2, N_2, H_2O) in flue gas	decimal
7B	HCL	}	
7B	S02	}	
7B	02	}	
7B	N2	}	
7B	H20	}	
7B	SCFM(1)	Standard cubic feet per minute (60°F), gas from boiler	sft3/min
7B	WASH	Pounds of ash per hour in hot gas from boiler	lb/hr
8	IBYPAS	Bypass flag	0 = no bypass 1 = bypass
8	REHEAT	Reheat temperature	$^{\circ}$F
8	IXS02	Controlled outlet emission flag	
		Controlled outlet emission calculation in accordance with 1979 NSPS regulations (in lb SO_2/MBtu) if IREM also = 0	0
		Controlled outlet emission calculated based on input regulation (in lb SO_2/MBtu) using AXS02	1

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
8	AXSO2	Input value for the controlled outlet emission (for IXSO2 = 1)	lb SO_2/MBtu
8	IREM	Percent SO_2 removal flag % SO_2 removal efficiency in accordance with the 1979 NSPS regulations (if also IXSO2 = 0) % SO_2 removal efficiency input using REMSO2	 0 1
8	REMSO2	Input value for the percent SO_2 removal (for IREM = 1)	%
9	NOPSD	Number of operating spray dryers	1-10
9	NSPSD	Number of spare spray dryers	0-10
9	SO4SPL	$CaSO_4$ in spray dryer bottom discharge	wt %
9	PARSPL	Particulates (less $CaSO_4$) in spray dryer discharge flue gas	wt %
9	SO3OX	Oxidation of $CaSO_3$ to $CaSO_4$ in spray dryer	%
9	TAPSAT	Approach-to-saturation temperature	°F
9	SDRES	Spray dryer residence time	sec
9	SDPRES	Spray dryer pressure drop	in. H_2O
10	WPCAO	Weight percent CaO in alkali	wt %
10	WPINER	Weight percent inerts in alkali	wt %
10	WPH2OL	Weight percent H_2O in alkali	wt %
10	WPMGOL	Weight percent MgO in alkali	wt %
10	SLKEFF	Slaker efficiency, conversion of CaO to $Ca(OH)_2$	%
11	ICASTO	Lime stoichiometry flag Lime stoichiometry calculated Lime stoichiometry input	 0 1

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TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
11	CAOSTO	Lime stoichiometry	mols CaO/mol SO_2 at economizer outlet
11	NSPREP	Number of spare feed preparation units	0-10
11	IBALML	Inerts removal flag	
		Inerts removed from lime slurry	0
		Inerts retained in lime slurry	1
11	XLMPCT	Weight percent solids in fresh lime slurry	wt %
11	RCYPCT	Weight percent solids in recycle slurry	wt %
12	IPART	Particulate removal cost flag	
		Costs excluded	0
		Costs included	1
12	NTBAGH	Number of baghouses	1-10
12	BHPRES	Baghouse pressure drop	in. H_2O
12	BAGRAT	Baghouse ratio (typically = 0.8)	$\frac{\text{operating compartments}}{\text{total compartments}}$
12	BGCOST	Bag cost	$/ft^2
12	AC	Air-to-cloth ratio	aft3/min/ft^2 cloth area
12	BAGCOM	Baghouse compartments	1-50
13	UC(2)	Lime unit cost	$/ton
13	UC(3)	Process labor and supervision unit cost	$/man-hr
13	UC(4)	Landfill labor and supervision unit cost	$/man-hr

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TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
13	UC(5)	Boiler heat loss	$/MBtu
13	UC(6)	Process water unit cost	$/kgal
13	UC(7)	Electricity unit cost	$/kWh
13	UC(8)	Diesel fuel unit cost	$/gal
13	UC(9)	Analysis unit cost	$/man-hr
13	II	Construction schedule	yr
13	TPI(II)	Plant, fraction of capital investment per year	decimal
14	INVYR	Investment year cost basis	yr
14	IREVYR	Revenue requirement year cost basis	yr
14	IOPSCH	Operating profile option TVA profile Levelized profile Capacity factor profile User input profile	 1 2 3 4
14	IYROP	Years remaining life (lines 20-24 are needed only if the IOPSCH variable above is set to 4, up to 50 years may be input).	
14	ICLEV	Optional calculation of levelizing factor and levelized capital charges Input values processed (UNDCAP, FACLEV) Calculated values processed	 0 1
14	IDCAL	Optional calculation of interest during construction Input values processed (CONINT) Calculated values processed	 0 1
14	ONCAP	Capacity factor (onstream time/available time)	%

(Continued)

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TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
15	ENGIN	Engineering design and supervision	%
15	ARCTEC	Architect and engineering contractor	%
15	FLDEXP	Construction field expenses	%
15	FEES	Contractor fees	%
15	CONT	Contingency	%
15	START	Allowance for startup and modifications	%
15	CONINT	Interest during construction	%
15	XINT	Cost of capital	%
15	PCTMNT	Maintenance rate, applied as percent of direct investment excluding landfill construction direct costs	
16	SENGIN	Landfill construction design and supervision	%
16	SARCH	Landfill construction architect and engineering contractor	%
16	SFLDEX	Landfill construction field expenses	%
16	SFEES	Landfill construction contractor fees	%
16	SCONT	Landfill construction contingency	%
16	SSTART	Allowance for landfill startup and modifications	%
16	PDMNTP	Landfill maintenance rate, applied as percent of landfill direct investment	%

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
16	SDCAP	Expected landfill site capacity (controls site design capacity; if 100% of waste is to be disposed over the life of the unit, input 100; if landfill site is to be prorated for FGD waste only, input percent of waste to be included in the cost estimate for the disposal site) (i.e., 80%).	%
17	XINFLA	Inflation factor	%
17	PCTOVR	Plant overhead rate, applied as percent of conversion costs less utilities	%
17	FACLEV	Specifies the levelizing factor to be applied to first-year operating and maintenance costs to obtain levelized lifetime costs. If FACLEV is set to zero, levelizing is not applied and a lifetime revenue table is generated.	%
17	UNDCAP	Levelized annual capital charge applied as a percent of total capital investment.	%
17	PCTINS	Specifies marketing costs applied as a percent of byproduct credit. (Applies only to processes with a salable byproduct.)	%
17	ITAXFR	Sales tax and freight option	
		No sales tax or freight	0
		Sales tax and rate applied as listed below	1
17	TXRAT	Sales tax rate (applied only when ITAXFR is set to one)	%
17	FRRAT	Freight rate (applied only when ITAXFR is set to one)	%

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
17	SERVRT	Services, utilities, and miscellaneous applied as a percent of total process capital	%
17	ROYAL	Royalties applied as a percent of total process capital	%
18	ACRE$	Land cost	$/acre
18	DISTLF	Distance from scrubber area to disposal site	ft
18	ILINER	Disposal site lining option	
		Clay liner	1
		Synthetic liner	2
		No liner	3
18	XLINA	If ILINER = 1, XLINA = clay depth	in.
		If ILINER = 2, XLINA = material cost	$/yd^2
		If ILINER = 3, XLINA = 0	
18	XLINB	If ILINER = 1, XLINB = clay cost	$/yd^3
		If ILINER = 2, XLINB = labor unit cost	$/yd^2
		If ILINER = 3, XLINB = 0	
19	IOTIME	Overtime labor option	
		No overtime labor	0
		Overtime labor on 7% of total labor based on the OTRATE rate below	1
19	OTRATE	Overtime labor rate (applied to 7% of total labor) (typically = 1.5)	decimal
19	RETRO	Retrofit factor	decimal
19	CNDXM	_Chemical Engineering_ material cost index	
19	CNDXL	_Chemical Engineering_ labor cost index	
19	CNDXP	_Chemical Engineering_ plant cost index	

(Continued)

TABLE C-2. (Continued)

Line	Variable	Definition	Unit or value
20	IA(1) - IA(10)	Operating hr/yr (input only 10 years per line)	hr
21	IA(11) - IA(20)	Operating hr/yr (input only 10 years per line)	hr
22	IA(21) - IA(30)	Operating hr/yr (input only 10 years per line)	hr
23	END OR NEXT	"END" terminates further execution. "NEXT" execution will continue with the next group of input variables. (If variable IOPSCH above is not equal to 4, line 20 will be the end or next line.)	

Appendix D

BASE CASE LIME SPRAY DRYER COMPUTER MODEL INPUT AND PRINTOUT

TABLE D-1. BASE CASE LIME SPRAY DRYER

COMPUTER MODEL PRINTOUT

```
1 1 1 1 1 1 1
1 1 1 1
1 1 1 1 1 1 1 1
1 1 1 1
500 10500 8200 20 18 14.7 95 80 700 300 0
49.0 0.02 0.48 3.5 10.7 0.7 29.3 6.3
1 168 0 0 1 70
3 1 75 66 25 18 10 2
95 4.85 5.0 0.15 100
0 0 1 0 25.0 35.0
1 2 6 0.8 0.75 2.0 10
90 19 24 5.3 0.16 0.055 1.6 26 3 .35 .5 .25
1985 1987 2 30 0 0 62.0
7 2 16 5 20 10 15.6 10 6
2 1 8 5 20 0 3 100
6 60 1.886 15.6 0.0 1 4 3.5 6 1
6000 5280 1 12 6
1 1.5 1.0 366.8 292.2 346.
END
```

TABLE D-1. (Continued)

TENNESSEE VALLEY AUTHORITY
SPRAY DRYER FLUE GAS DESULFURIZATION PROCESS
COMPUTERIZED DESIGN-COST ESTIMATE MODEL

REVISION DATE: 08/01/85

(Continued)

TABLE D-1. (Continued)

```
BOILER CHARACTERISTICS
------ ---------------

   MEGAWATTS =    500

   BOILER HEAT RATE = 10500.

   EXCESS AIR = 20. PERCENT

   AIR HEATER INLEAKAGE = 19. PERCENT

   HOT GAS TEMP. (ECONOMIZER EXIT) =  700. DEG F

   WARM GAS TEMP (AIR HEATER EXIT) =  300. DEG F

COAL ANALYSIS, WT % AS FIRED:
---- --------  --------------

     C       H       O       N       S      CL     ASH     H2O
   49.00   3.50  10.70   0.70   0.48   0.02   6.30  29.30

   HEATING VALUE OF COAL = 8200. BTU/LB

   SULFUR OVERHEAD =  85.0 PERCENT

   ASH OVERHEAD    =  80.0 PERCENT

LIME ANALYSIS
---- --------

   CAO    = 95.00 WT % DRY BASIS

   MGO    =  0.15

   INERTS =  4.85

   MOISTURE CONTENT =  5.00 LB H2O/100 LBS DRY LIME

BAGHOUSE
--------


   NUMBER OF BAGHOUSES =   2

   NUMBER OF COMPARTMENTS PER BAGHOUSE = 10.

   NUMBER OF OPERATING COMPARTMENTS PER BAGHOUSE =  8.

   AIR TO CLOTH RATIO (OPERATING) = 2.00 ACFM/FT2

   COST PER BAG ($/FT2) =  0.750

   BAGHOUSE PRESSURE DROP (MAX) = 6.0 IN. H2O
```

(Continued)

TABLE D-1. (Continued)

```
SYSTEM DESIGN PARAMETERS
------ ------ ----------

   BYPASS OPTION SELECTED

   REHEAT TEMPERATURE =  168.0 DEG F

   APPROACH TO SATURATION TEMPERATURE =  18.0 DEGREES F

   PERCENT OF CASO4 WHICH EXITS THE SPRAY DRYER THROUGH THE BOTTOM = 75.0

   PERCENT OF PARTICULATES (LESS CASO4) WHICH EXITS THE SPRAY DRYER WITH THE FLUE GAS = 66.0

   PERCENT OXIDATION OF CASO3 TO CASO4 =  25.0

   SPRAY DRYER RESIDENCE TIME (SECONDS) = 10.0

   NUMBER OF OPERATING SPRAY DRYERS =  3

   NUMBER OF SPARE SPRAY DRYERS =  1

   SO2 REMOVAL PERCENTAGE OVERRIDE SELECTED
        SO2 REMOVAL =  70.0 PERCENT

   LIME INERTS REMOVED WITH A CLASSIFIER AND TAKEN TO DISPOSAL

   NUMBER OF REDUNDANT FEED PREPARATION SYSTEMS =   1

   SLAKING EFFICIENCY, CONVERSION OF CAO TO CA(OH)2 = 100.0 PERCENT

   SLAKER DISCHARGE LIME SLURRY SOLIDS PERCENTAGE =  25.0

   SPRAY DRYER RECYCLE SLURRY SOLIDS PERCENTAGE =    35.0

LANDFILL PARAMETERS
-------- ----------


   LAND COST = 6000. $/ACRE

   DISTANCE TO LANDFILL =  5280.0 FEET

   CLAY DEPTH = 12.0 INCHES

   CLAY COST =  6.00 $/YD3

   EXPECTED LANDFILL CAPACITY = 100.0 % OF LIFETIME GENERATING CAPACITY
```

(Continued)

TABLE D-1. (Continued)

```
ECONOMIC PREMISES
-------- --------
 PROCESS
 -------

    SERVICES, UTILITIES, AND MISCELLANEOUS =      6.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    ENGR. DESIGN AND SUPERVISION =                7.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    ARCHITECT AND ENGR. CONTRACTOR =              2.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    CONSTRUCTION EXPENSE =                       16.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    CONTRACTOR FEES =                             5.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    CONTINGENCY =                                20.0 % OF TOTAL PROCESS DIRECT PLUS INDIRECT INVESTMENT
    ALLOWANCE FOR STARTUP AND MODIFICATIONS =    10.0 % OF TOTAL FIXED PROCESS INVESTMENT
    ROYALITIES =                                  1.0 % OF TOTAL PROCESS CAPITAL
    PROCESS MAINTENANCE =                         6.0 % OF TOTAL DIRECT PROCESS INVESTMENT
    LEVELIZING FACTOR =                           1.886 (APPLIED TO FIRST YEAR OPERATING AND MAINTENANCE COSTS)
    LEVELIZED ANNUAL CAPITAL CHARGE =            15.6 % OF TOTAL CAPITAL INVESTMENT
 LANDFILL
 --------

    ENGR. DESIGN AND SUPERVISION =              2.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
    ARCHITECT AND ENGR CONTRACTOR =             1.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
    CONSTRUCTION EXPENSE =                      8.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
    CONTRACTOR FEES =                           5.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
    CONTINGENCY =                              20.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
    ALLOWANCE FOR STARTUP AND MODIFICATION =    0.0 % OF TOTAL LANDFILL DIRECT PLUS INDIRECT INVESTMENT
    LANDFILL MAINTENANCE =                      3.0 % OF TOTAL DIRECT LANDFILL INVESTMENT
 GENERAL
 -------

    INTEREST DURING CONSTRUCTION =            15.6 %
    COST OF CAPITAL =                         10.0 %
    OVERTIME RATE APPLIED TO LABOR =           1.5
    TAX RATE APPLIED TO MATERIAL COST =        4.0 %
    FREIGHT RATE APPLIED TO MATERIAL COST =    3.5 %
    INFLATION RATE =                           6.0 %
```

(Continued)

TABLE D-1. (Continued)

MATERIAL BALANCE - COMBUSTION RELATED

**** OUTPUTS ****

STREAM NO.	1	2	3	4	5	6	7
STREAM TITLE	COAL TO BOILER	TOTAL AIR TO AIR HEATER	COMBUSTION AIR TO BOILER	BOTTOM ASH	GAS TO ECONOMIZER	GAS FROM ECONOMIZER	GAS TO AIR HEATER
N2 (C) LB/HR	(313719.)	4375601.	3777497.		3781977.	3781977.	3781977.
O2 (H) LB/HR	(22409.)	1318089.	1137919.		189653.	189653.	189653.
CO2 (C) LB/HR	(68506.)				1149607.	1149607.	1149607.
SO2 (N) LB/HR	(4482.)				5219.	5219.	5219.
HCL (CL) LB/HR	(128.)				132.	132.	132.
(S) LB/HR	(3073.)						
H2O LB/HR	187591.	76182.	65768.		453581.	453581.	453581.
PARTICULATE LB/HR	40335.			8159.	32637.	32637.	32637.
TOTAL LB/HR FLOW RATE	640243.	5769871.	4981184.	8159.	5612804.	5612804.	5612804.
SCFM (ATM.,60 F)		1275670.	1101297.		1216848.	1216848.	1216848.
ACFM		1324371.	2106714.		3158261.	2713766.	2713766.
GAS TEMP.(DEG. F)		80.	535.		890.	700.	700.

STREAM NO.	8	9	10	11	12	13	14
STREAM TITLE	AIR INLEAKAGE	GAS TO SPRAY DRYER	GAS FROM SPRAY DRYER	BYPASS (WARM GAS)	GAS TO BAGHOUSE	GAS TO FAN	GAS TO STACK
N2 LB/HR	598104.	3935111.	3935111.	444968.	4380079.	4380079.	4380079.
O2 LB/HR	180170.	332253.	332042.	37570.	369612.	369612.	369612.
CO2 LB/HR		1032819.	1032667.	116788.	1149454.	1149454.	1149454.
SO2 LB/HR		4689.	1312.	530.	1842.	1842.	1842.
HCL LB/HR		118.	6.	13.	19.	19.	19.
H2O LB/HR	10413.	416857.	629364.	47137.	676501.	676501.	676501.
PARTICULATE LB/HR		29321.	88289.	3316.	91605.	158.	158.
TOTAL LB/HR FLOW RATE	788688.	5751169.	6018789.	650322.	6669110.	6577663.	6577663.
SCFM (ATM.,60 F)	174372.	1249888.	1324117.	141333.	1465450.	1465450.	1465450.
ACFM	333563.	1826260.	1562305.	206507.	1769330.	1769330.	1786268.
GAS TEMP.(DEG. F)	535.	300.	154.	300.	168.	168.	174.

(Continued)

TABLE D-1. (Continued)

```
SPRAY DRYER INLET AND OUTLET COMPONENT VOLUME PERCENTAGE
--------------------------------------------------------

                     STREAM 9         STREAM 10

                      GAS TO          GAS FROM
                      SPRAY            SPRAY
                      DRYER            DRYER

 N2 VOL %            71.1069          67.1207
 O2 VOL %             5.2570           4.9592
CO2 VOL %            11.8822          11.2144
SO2 VOL %             0.0371           0.0098
HCL VOL %             0.0016           0.0001
H2O VOL %            11.7153          16.6959


SO2 EMISSIONS                                                               NSPS       ACTUAL
--- ---------                                                               ----       ------

  EQUIVALENT SO2 CONTENT OF THE RAW COAL (LB SO2/MBTU):                      1.17        1.17

  SO2 CONTROLLED OUTLET EMISSION STANDARD (LB SO2/MBTU):                     0.35        0.35

  EQUIVALENT SO2 REMOVAL REQUIREMENT FOR ENTIRE PLANT:                      70.00       70.00

  EQUIVALENT SO2 REMOVAL REQUIREMENT IN FGD SYSTEM
       INCLUDING BYPASSED FLUE GAS:                                         64.71       64.71

SPRAY DRYER PERFORMANCE
----- ----- -----------

  WARM GAS BYPASS PERCENTAGE = 10.2 %

  SPRAY DRYER SO2 REMOVAL (ACTUAL) = 72.0 %

  SPRAY DRYER SATURATION TEMP. = 135.7 DEG. F

  SPRAY DRYER EXIT TEMP. = 153.7 DEG. F

  CAC STOICHIOMETRY = 0.732 MOLE CA(OH)2 / MOLE SO2 OUT OF BOILER

  TOTAL LIME USAGE (INCLUDES STABILIZATION OF THE HCL REMOVED IN THE SPRAY DRYER) =    3794. LBS/HR

  RECYCLE RATIO = 21.233 LBS OF RECYCLE SOLIDS/FRESH LB CA(OH)2

BAGHOUSE PERFORMANCE
-------- -----------

  NSPS PARTICULATE EMISSION STANDARD = 0.03 LB/MBTU

  BAGHOUSE PARTICULATE REMOVAL EFFICIENCY = 99.83 %

  PLANT PARTICULATE EMISSION (LB/MBTU) = 0.030

  PLANT PARTICULATE EMISSION (LB/HR) = 157.50
```

(Continued)

TABLE D-1. (Continued)

MATERIAL BALANCE - DFGD PROCESS PELATED

STREAM NO.	15	16	17	18	19	20	21
STREAM TITLE	LIME TO SLAKER	WATER TO SLAKER	INERTS TO DISPOSAL	SLAKED LIME TO COMBINED FEED TANK	PARTICULATES REMOVED BY SPRAY DRYER	SPRAY DRYER PARTICULATES TO DISPOSAL SILO	SPRAY DRYER PARTICULATES TO RECYCLE SILO
CASO4*2(H2O) LB/HR					15287.	0.	15287.
CASO3*1/2(H2O)LB/HR					4162.	0.	4162.
CACO3 LB/HR					283.	0.	283.
CACL2 LB/HR					139.	0.	139.
CA(OH)2 LB/HR				4535.	210.	0.	210.
CAO LB/HR	3433.						
MGO LB/HR	5.			5.	4.	0.	4.
ASH (INERTS) LB/HR	(175.)		(175.)	(0.)	25396.	0.	25396.
H2O LB/HR	181.	14544.		13622.			
TOTAL LB/HR	3794.	14544.	175.	18162.	45482.	0.	45482.
GPM		29.		31.			
PERCENT SOLIDS		0.0		25.0			
SPECIFIC GRAVITY		1.000		1.161			

STREAM NO.	22	23	24	25	26	27	28
STREAM TITLE	TOTAL BAGHOUSE PARTICULATES	BAGHOUSE PARTICULATES TO DISPOSAL SILO	BAGHOUSE PARTICULATES TO RECYCLE SILO	TOTAL PARTICULATES TO LANDFILL	WATER FOR RECYCLE SLURRY	RECYCLE SLURRY TO COMBINED FEED TANK	COMBINED FEED SLURRY TO SPRAY DRYER
CASO4*2(H2O) LB/HR	5087.	2260.	2926.	2260.		18113.	23547.
CASO3*1/2(H2O)LB/HR	11447.	5087.	6360.	5087.		10522.	13679.
CACO3 LB/HR	779.	346.	433.	346.		716.	931.
CACL2 LB/HR	384.	170.	213.	170.		353.	458.
CA(OH)2 LB/HR	577.	256.	321.	256.		530.	6585.
CAO LB/HR							
MGO LB/HR	12.	5.	7.	5.		11.	22.
ASH (INERTS) LB/HR	73161.	32511.	40650.	32686.		66046.	65860.
H2O LB/HR					178829.	178829.	250185.
TOTAL LB/HR	91447.	40637.	50810.	40812.	178829.	275121.	361268.
GPM					358.	422.	585.
PERCENT SOLIDS					0.0	35.0	34.4
SPECIFIC GRAVITY					1.000	1.304	1.294

(Continued)

TABLE D-1. (Continued)

STREAM NO. STREAM TITLE	29 OVERFLOW RETURN TO COMBINED FEED TANK	30 COMBINED FEED SLURRY TO ATOMIZER	31 ATOMIZER DILUTION WATER				
CASO4·2(H2O) LB/HR	5434.	18113.					
CASO3·1/2(H2O) LB/HR	3157.	10522.					
CACO3 LB/HR	215.	716.					
CACL2 LB/HR	106.	353.					
CAOH2 LB/HR	1520.	5065.					
CAO LB/HR							
MGO LB/HR	5.	17.					
ASH (INERTS) LB/HR	19814.	56046.					
H2O LB/HR	57735.	192450.	20000.				
TOTAL LB/HR	87985.	293283.	20000.				
GPM	136.	453.	40.				
PERCENT SOLIDS	0.3	0.3	0.0				
SPECIFIC GRAVITY	1.294	1.294	1.000				

(Continued)

TABLE D-1. (Continued)

DFGD SYSTEM EQUIPMENT LIST

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 1 -- MATERIAL HANDLING		
1. CAR SHAKER AND CRANE (1): TOP MOUNTING WITH CRANE, 20.0-HP SHAKER, 7.5-HP HOIST	85232.	14392.
2. CAR PULLER (1): 25-HP PULLER, 5.0-HP RETURN	70391.	21586.
3. HOPPER, LIME UNLOADING (1): 16-FT DIA. X 10-FT STRAIGHT SIDE, CARBON STEEL 60-DEGREE CONE BOTTOM, INCLUDES 6-IN. SQUARE GRATING	16566.	6837.
4. FEEDER, LIME UNLOADING (1): VIBRATING PAN, 3.5-HP, 100 TONS/HR, CARBON STEEL	6987.	588.
5. CONVEYOR, LIME UNLOADING (1): BELT, 36-IN. WIDE X 20-FT LONG, 5.0-HP, 100 TONS/HR	11490.	1639.
6. ELEVATOR, LIME UNLOADING (1): CONTINUOUS BUCKET, 25.0-HP, 92.-FT LIFT, 100 TONS/HR	45613.	3778.
7. SILO, LIME STORAGE (1): 35.-FT DIA. X 52.-FT STRAIGHT SIDE HEIGHT, 49667. FT3, CONCRETE CONSTRUCTION	79051.	142664.
8. HOPPER, LIME STORAGE SILO (1): 60-DEGREE CONE, CARBON STEEL	12210.	9255.
9. FEEDER, RECLAIM (1): VIBRATING PAN, 3.5-HP, 1.9 TONS/HR	5174.	452.
10. CONVEYOR, RECLAIM (1): BELT, 18-IN. WIDE X 110.-FT LONG, 5.0-HP, 1.9 TONS/HR	25518.	3595.
11. ELEVATOR, RECLAIM (1): CONTINUOUS BUCKET, 1.0-HP, 28.-FT LIFT, 1.9 TONS/HR	44666.	2543.
12. BIN, LIME FEED (2): 9.-FT DIA. X 13.-FT STRAIGHT SIDE HEIGHT, COVERED, 60-DEGREE CONE HOPPER, CARBON STEEL	8656.	5585.
13. DUST COLLECTOR, LIME UNLOADING PIT (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN, INCLUDES DUST HOOD	10862.	5922.
14. DUST COLLECTOR, LIME UNLOADING PIT (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	429707.	221796.

(Continued)

TABLE D-1. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 1 -- FEED PREPARATION		
1. FEEDER, LIME FEED BIN (2): BIN ACTIVATOR, 6-FT DIAMETER, 2.0-HP	26025.	2961.
2. CONVEYOR, LIME FEED BIN (2): SCREW, 12-IN. DIA. X 12-FT LONG, 1.0-HP, 1.9 TONS/HR	12008.	1695.
3. SLAKER (2): BALL-MILL TYPE, 31.-HP, 1.9 TONS/HR INCLUDES CLASSIFIER	105167.	17326.
4. TANK, SLAKER PRODUCT (1): 14.1-FT DIA. X 14.1-FT HIGH, 16518. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	11291.	9421.
5. AGITATOR, SLAKER PRODUCT TANK (1): 10.0-HP	11739.	972.
6. PUMP, SLAKER PRODUCT TANK (3): CENTRIFUGAL, 16. GPM, 1.0-HP, CARBON STEEL, NEOPRENE LINED (2 OPERATING, 1 SPARE)	7046.	1017.
7. FEEDER, SPRAY DRYER RECYCLE SILO (1): SCREW, 19.-IN. DIA. X 20-FT LONG, 5.0-HP, 22.7 TONS/HR	13659.	2315.
8. FEEDER, BAGHOUSE RECYCLE SILO (1): SCREW, 20.-IN. DIA. X 20-FT LONG, 5.0-HP, 25.4 TONS/HR	14706.	2493.
9. TANK, RECYCLE SLURRY (1): 42.3-FT DIA. X 21.2-FT HIGH, 222640. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	68210.	56245.
10. AGITATOR, RECYCLE SLURRY TANK (1): 25.0-HP	65790.	5449.
11. PUMP, RECYCLE SLURRY TANK (3): CENTRIFUGAL, 211. GPM, 10.0-HP, CARBON STEEL, NEOPRENE LINED (2 OPERATING, 1 SPARE)	12238.	4748.
12. TANK, COMBINED FEED (1): 17.2-FT DIA. X 8.6-FT HIGH, 14947. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	9611.	8035.
13. AGITATOR, COMBINED FEED TANK (1): 3.5-HP	11042.	515.
14. PUMP, COMBINED FEED TANK (2): CENTRIFUGAL, 588. GPM, 20.0-HP, CARBON STEEL, NEOPRENE LINED (1 OPERATING, 1 SPARE)	12619.	4957.
	385349.	118548.

(Continued)

TABLE D-1. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 3 -- GAS HANDLING		
1. FAN (4): INDUCED DRAFT, 442333. ACFM, 13.8-IN. STATIC HEAD, 1372.-HP	1371901.	63825.
	1371901.	63825.
AREA 4 -- SO2 ABSORPTION		
1. TANK, HEAD (4): 2.3-FT DIA. X 5.9-FT HIGH, 216. GAL., OPEN TOP, CARBON STEEL, NEOPRENE LINED	3526.	2939.
2. SPRAY DRYER (4): 48.7-FT DIA. X 34.6-FT STRAIGHT SIDE HEIGHT, 520768. ACFM, 60 DEGREE CONICAL HOPPER, INCLUDES 700-HP ATOMIZER, (3 OPERATING, 1 SPARE)	6975179.	935901.
	6978705.	939840.
AREA 5 -- PARTICULATE REMOVAL		
1. BAGHOUSE (2): REVERSE AIR, 884665. ACFM, 2.00 OPERATING AIR-TO-CLOTH RATIO, 10. TOTAL COMPARTMENTS PER BAGHOUSE, 8. OPERATING COMPARTMENTS PER BAGHOUSE	6916993.	12061130.
2. CONVEYOR, BAGHOUSE PARTICULATE REMOVAL (4): BELT, 18-IN. WIDE X 235.-FT LONG, 3.5-HP, 11.4 TONS/HR (TWO PER BAGHOUSE)	171761.	23661.
3. CONVEYOR, BAGHOUSE PARTICULATE COLLECTION (1): BELT, 18-IN. WIDE X 78.-FT LONG, 3.5-HP, 45.7 TONS/HR	34649.	4661.
4. ELEVATOR, BAGHOUSE PARTICULATE COLLECTION (1): CONTINUOUS BUCKET, 7.5-HP , 25.-FT LIFT, 45.7 TONS/HR	19800.	1135.
5. BIN, BAGHOUSE PARTICULATE SURGE (2): 7.-FT DIA. X 11.-FT STRAIGHT SIDE HEIGHT, COVERED, 45-DEGREE CONE HOPPER, CARBON STEEL, INCLUDES HOPPER HEATER	6149.	3793.
6. CONVEYOR, BAGHOUSE PARTICULATE DISPOSAL (1): PNUEMATIC, PRESSURE, 250.0-HP	234281.	80846.
7. SILO, PARTICULATE DISPOSAL (1): 20.-FT DIA. X 30.-FT STRAIGHT SIDE HEIGHT, 9795. FT3, CONCRETE CONSTRUCTION	33678.	60099.
8. HOPPER, PARTICULATE DISPOSAL SILO (1): 45-DEGREE CONE, CARBON STEEL	6217.	3496.
9. DUST COLLECTOR, PARTICULATE DISPOSAL SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7252.	2961.
	7432817.	12241778.

(Continued)

TABLE D-1. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 6 -- SPRAY DRYER SOLIDS HANDLING		
1. CONVEYOR, SPRAY DRYER PARTICULATE (4): DRAG-LINK, 24-IN. WIDE X 15.-FT LONG, 3.5-HP, 22.7 TONS/HR, ENCLOSED	136448.	5777.
2. CONVEYOR, REJECT CONVEYOR (1): BELT, 24-IN. WIDE X 235.-FT LONG, 5.0-HP, 22.7 TONS/HR	44307.	6122.
3. CONVEYOR, SPRAY DRYER PARTICULATE COLLECTION (1): BELT, 24-IN. WIDE X 235.-FT LONG, 5.0-HP, 22.7 TONS/HR	44307.	6122.
4. ELEVATOR, SPRAY DRYER PARTICULATE COLLECTION (1): CONTINUOUS BUCKET, 2.0-HP , 25.-FT LIFT, 22.7 TONS/HR	8023.	1064.
5. BIN, SPRAY DRYER PARTICULATE SURGE (1): 7.-FT DIA. X 11.-FT STRAIGHT SIDE HEIGHT, COVERED, 45-DEGREE CONE HOPPER, CARBON STEEL, INCLUDES HOPPER HEATER	2065.	1690.
6. CONVEYOR, SPRAY DRYER PARTICULATE TRANSFER (1): PNUEMATIC, PRESSURE, 100.0-HP	119409.	40961.
7. SILO, SPRAY DRYER PARTICULATE RECYCLE (1): 21.-FT DIA. X 32.-FT STRAIGHT SIDE HEIGHT, 10916. FT3, CONCRETE CONSTRUCTION	35413.	63664.
8. HOPPER, SPRAY DRYER PARTICULATE RECYCLE SILO (1): 45-DEGREE CONE, CARBON STEEL	8947.	3790.
9. DUST COLLECTOR, SPRAY DRYER PARTICULATE RECYCLE SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS, 2200 CFM, 7.5-HP FAN	7292.	2961.
	----------	----------
	406212.	132292.

(Continued)

TABLE D-1. (Continued)

ITEM (QUANITY): DESCRIPTION	MATERIAL COST 1985$	LABOR COST 1985$
AREA 7 -- BAGHOUSE SOLIDS RECYCLE		
1. CONVEYOR, BAGHOUSE PARTICULATE RECYCLE (1): PNUEMATIC, PRESSURE, (ADD-ON TO BAGHOUSE PARTICULATE DISPOSAL CONVEYOR (AREA 5, NO. 6) INCLUDES Y-DIVERTER VALVE, PIPING, ETC.)	13965.	2982.
2. SILO, BAGHOUSE PARTICULATE RECYCLE (1): 22. FT DIA. X 33. FT STRAIGHT SIDE HEIGHT, 12194. FT3, CONCRETE CONSTRUCTION	37766.	67930.
3. HOPPER, BAGHOUSE PARTICULATE RECYCLE SILO (1): 45-DEGREE CONE, CARBON STEEL	9394.	4547.
4. DUST COLLECTOR, BAGHOUSE PARTICULATE RECYCLE SILO (1): 16-OZ POLYESTER FELT CLOTH BAGS 2200 CFM, 7.5-HP FAN	7292.	2961.
	----------	----------
	68417.	77520.

(Continued)

TABLE D-1. (Continued)

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LANDFILL DESIGN
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LANDFILL DIMENSIONS
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HEIGHT OF LANDFILL                    89.67 FT
HEIGHT OF LANDFILL CAP                69.67 FT
SLOPE OF LANDFILL CAP                  5.   DEGREES
LENGTH OF LANDFILL DISPOSAL SIDE    1425.   FT
LENGTH OF LANDFILL TRENCH           5849.   FT
LENGTH OF PERIMETER FENCE           7651.   FT

SURFACE AREA OF LANDFILL            2069.   THOUSAND FT2
FILL AREA LAND EXPOSED TO RAIN      2193.   THOUSAND FT2
SURFACE AREA OF RECLAIM STORAGE      329.   THOUSAND FT2
DISPOSAL LAND AREA OF LANDFILL      2033.   THOUSAND FT2
LAND AREA OF LANDFILL SITE          3094.   THOUSAND FT2
LAND AREA OF LANDFILL SITE            71.   ACRES

VOLUME OF EXCAVATION                 181.   THOUSAND YD3
VOLUME OF RECLAIM STORAGE            179.   THOUSAND YD3
VOLUME OF SLUDGE TO HE              2934.   THOUSAND YD3
 DISPOSED OVER LIFE OF PLANT        1819    ACRE FT

DENSITY OF DISCHARGE CAKE             70.00 LBS/FT3
DENSITY OF COMPACTED CAKE             85.00 LBS/FT3

DEPTH OF CATCHMENT POND               23.36 FT
LENGTH OF CATCHMENT POND             302.19 FT
VOLUME OF CATCHMENT POND              57.   THOUSAND YD3
```

(Continued)

TABLE D-1. (Continued)

LANDFILL EQUIPMENT

ITEM	DESCRIPTION	NO.	MATERIAL	LABOR
TRUCKS	16.0 CU YD,1 SPARE	2	101623.	0.
WHEEL LOADER	3.0 CU YDS-BUCKET	1	119592.	0.
TRACK-DOZER	86.HP,STRAIGHT-BLADE	1	95594.	0.
COMPACTOR	SHEEP-FOOT	1	118776.	0.
WHEEL LOADER	1.5 CU YDS BUCKET CLEANUP	1	77122.	0.
WATER TRUCK	1500 GALLON TANK AND SPRAY HEADERS	1	37990.	0.
SERVICE TRUCK	WRECKER RIG, TOOLS	1	30570.	0.
TRAILER	12 FT X 30 FT, OFFICE BREAKROOM,FACILITIES	1	10917.	1130.
WATER TREATMENT SYSTEM	PUMPS, TANKS		20953.	16545.
EQUIPMENT TOTAL			613138.	17675.

(Continued)

TABLE D-1. (Continued)

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LANDFILL COSTS (THOUSANDS OF DOLLARS)
-------- ----- ---------- -- --------


LANDFILL EQUIPMENT                                            631.
TAX AND FREIGHT                                                46.

LANDFILL EQUIPMENT TOTAL                                      677.
------------------------------------------------------------------
                                   LABOR    MATERIAL    TOTAL
                                   -----    --------    -----

CLEARING LAND                       156.                 156.
EXCAVATION                          357.                 357.
DISCHARGE TRENCH                     19.                  19.
GRAVEL                               40.       47.        86.
LINING( 12. IN. CLAY)               562.                 562.
DRAINAGE LANDFILL                     7.       66.        73.
SEEDING LANDFILL SITE                58.       34.        92.
ROAD CONSTRUCTION                    71.       41.       112.
PERIMETER COSTS, FENCE               52.       58.       111.
RECLAMATION EXPENSE                 156.                 166.
RECLAMATION CLAY COVER              260.                 260.
MONITOR WELLS                         6.        5.        11.
------------------------------------------------------------------
SUBTOTAL DIRECT                    1754.      251.      2006.
TAX AND FREIGHT                                19.        19.
------------------------------------------------------------------
TOTAL DIRECT LANDFILL INVESTMENT   1754.      270.      2025.
------------------------------------------------------------------
ENGINEERING DESIGN AND SUPERVISION ( 2.0 )                40.
ARCHITECT AND ENGINEERING CONTRACTOR( 1.0 )               20.
CONSTRUCTION EXPENSES.( 8.0 )                            162.
CONTRACTOR FEES ( 5.0 )                                  101.
CONTINGENCY (20.0 )                                      605.
------------------------------------------------------------------

TOTAL FIXED INVESTMENT                                  3631.

LAND COST                                                425.

REVENUE QUANTITIES
------- ----------


LANDFILL LABOR     24960.  MAN-HRS
DIESEL FUEL        48284.  GALLONS
ELECTRICITY        95294.  KWH
WATER               1905.  K-GALLONS
ANALYSIS              20.  MAN-HRS
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(Continued)

TABLE D-1. (Continued)

LIME SPRAY DRYER PROCESS -- BASIS: 500 MW SCRUBBING UNIT - 1987 STARTUP
PROJECTED CAPITAL INVESTMENT REQUIREMENTS - 0.7% S WESTERN SUBBITUMINOUS 500 MW

	INVESTMENT, THOUSANDS OF 1985 DOLLARS								DISTRIBUTION
	MAT HAND	FEED PREP	GAS HAND	SO2 ABSORB	PART REM	SD HAND	BAG RECYCLE	TOTAL	DOLLARS PER KW
EQUIPMENT									
MATERIAL	430.	385.	1372.	6979.	7433.	406.	68.	17073.	34.15
LABOR	222.	119.	64.	939.	12242.	132.	78.	13795.	27.59
PIPING									
MATERIAL	0.	49.	0.	265.	0.	0.	0.	314.	0.63
LABOR	0.	66.	0.	94.	0.	0.	0.	160.	0.32
DUCTWORK									
MATERIAL	0.	0.	4267.	0.	0.	0.	0.	4267.	8.53
LABOR	0.	0.	3052.	0.	0.	0.	0.	3052.	6.10
FOUNDATIONS									
MATERIAL	15.	23.	51.	235.	107.	10.	5.	447.	0.89
LABOR	27.	44.	92.	422.	194.	19.	9.	807.	1.61
STRUCTURAL									
MATERIAL	61.	13.	0.	0.	214.	4.	3.	295.	0.59
LABOR	17.	15.	0.	0.	318.	3.	1.	352.	0.70
ELECTRICAL									
MATERIAL	92.	108.	164.	85.	95.	79.	64.	688.	1.38
LABOR	51.	51.	626.	70.	39.	23.	15.	876.	1.75
INSTRUMENTATION									
MATERIAL	20.	124.	40.	262.	157.	30.	9.	642.	1.28
LABOR	2.	15.	4.	40.	70.	9.	1.	141.	0.28
BUILDINGS									
MATERIAL	34.	0.	0.	541.	0.	0.	0.	575.	1.15
LABOR	14.	0.	0.	221.	0.	0.	0.	235.	0.47
SALES TAX (4.0 %) AND FREIGHT (3.5 %)	49.	53.	442.	628.	600.	40.	11.	1823.	3.65
TOTAL PROCESS CAPITAL	1033.	1066.	10175.	10781.	21468.	756.	264.	45543.	91.09
SERVICES AND MISCELLANEOUS (6.0 %)	62.	64.	611.	647.	1288.	45.	16.	2733.	5.47
TOTAL DIRECT PROCESS INVESTMENT	1095.	1130.	10786.	11428.	22756.	801.	280.	48275.	96.55
LANDFILL EQUIPMENT	0.	0.	0.	0.	0.	0.	631.	631.	1.26
LANDFILL CONSTRUCTION	0.	0.	0.	0.	0.	0.	2006.	2006.	4.01
LANDFILL SALES TAX (4.0 %) AND FREIGHT (3.5 %)	0.	0.	0.	0.	0.	0.	65.	65.	0.13
TOTAL DIRECT INVESTMENT	1095.	1130.	10786.	11428.	22756.	801.	2981.	50977.	101.95
ENGINEERING DESIGN AND SUPERVISION (7.0 %)	77.	79.	755.	800.	1593.	56.	20.	3379.	6.76
ARCHITECT AND ENGINEERING CONTRACTOR (2.0 %)	22.	23.	216.	229.	455.	16.	6.	966.	1.93
CONSTRUCTION EXPENSES (16.0 %)	175.	181.	1726.	1829.	3641.	128.	45.	7724.	15.45
CONTRACTOR FEES (5.0 %)	55.	56.	539.	571.	1138.	40.	14.	2414.	4.83
CONTINGENCY (20.0 %)	285.	294.	2804.	2971.	5917.	208.	73.	12552.	25.10
LANDFILL INDIRECTS (2.0, 1.0, 8.0, 5.0, 20.0 %)	0.	0.	0.	0.	0.	0.	929.	929.	1.86
TOTAL FIXED INVESTMENT	1708.	1762.	16826.	17828.	35500.	1249.	4067.	78940.	157.88
STARTUP & MODIFICATION ALLOWANCE (10.0, 0.0 %)	171.	176.	1683.	1783.	3550.	125.	44.	7531.	15.06
INTEREST DURING CONSTRUCTION (15.6 %)	266.	275.	2625.	2781.	5538.	195.	634.	12315.	24.63
ROYALTIES (1.0 %)	10.	11.	102.	108.	215.	8.	3.	455.	0.91
LAND (6000. $/ACRE)	2.	2.	3.	2.	3.	1.	428.	440.	0.88
WORKING CAPITAL	58.	60.	576.	610.	1215.	43.	159.	2723.	5.45
TOTAL CAPITAL INVESTMENT	2216.	2286.	21814.	23112.	46021.	1620.	5335.	102404.	204.81

(Continued)

TABLE D-1. (Continued)

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     LIME SPRAY DRYER  -- BASIS:  500 MW SCRUBBING   UNIT -  500 MW GENERATING UNIT, 1987 STARTUP
PROJECTED REVENUE REQUIREMENTS -    0.7% S WESTERN SUBBITUMINUS  500 MW  -- BASE --                          C0010025
                                         DISPLAY SHEET FOR YEAR=    1
                                       ANNUAL OPERATION KW-HR/KW =  5500
                                                                                                  TOTAL
                                                        ANNUAL QUANTITY       UNIT COST,$         ANNUAL
      DIRECT COSTS                                      ---------------       -----------         COST,$
      ------------                                                                                ------
        RAW MATERIAL
        ------------
          LIME                                            10.4 K TONS          90.00/TON           939000
                                                                                                ----------
            SUBTOTAL RAW MATERIAL                                                                  939000
        CONVERSION COSTS
        ----------------
          OPERATING LABOR AND
            SUPERVISION                                  31410.0 MAN-HR        19.00/MAN-HR        596700
          LANDFILL LABOR AND
            SUPERVISION                                  24960.0 MAN-HR        24.00/MAN-HR        599000
          UTILITIES
            PROCESS WATER                               142670.0 K GAL          0.16/K GAL          22800
            ELECTRICITY                               34939710.0 KWH            0.055/KWH         1921700
            DIESEL FUEL                                  48280.0 GAL            1.60/GAL            77300
          MAINTENANCE
            LABOR AND MATERIAL                                                                    2977000
          ANALYSES                                        5330.0 HR            26.00/HR            138600
                                                                                                ----------
            SUBTOTAL CONVERSION COSTS                                                             6333700

            SUBTOTAL DIRECT COSTS                                                                 7272700
      INDIRECT COSTS
      --------------
        OVERHEADS
          PLANT AND ADMINISTRATIVE (  60.0% OF CONVERSION COSTS LESS UTILITIES)                   2587100
                                                                                                ----------
        FIRST YEAR OPERATING AND MAINTENANCE COSTS                                                9859800
        LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                           15975100
                                                                                                ----------
            FIRST YEAR ANNUAL REVENUE REQUIREMENTS                                               25834900

            EQUIVALENT FIRST YEAR UNIT REVENUE REQUIREMENTS, MILLS/KWH  (MW SCRUBBED)               9.39

            FIRST YEAR DOLLARS PER TON OF SULFUR REMOVED                                          5568.50
-------------------------------------------------------------------------------------------------------------------------
        LEVELIZED OPERATING AND MAINTENANCE ( 1.886 TIMES FIRST YEAR OPER. & MAIN.)              18595600
        LEVELIZED CAPITAL CHARGES( 15.60% OF TOTAL CAPITAL INVESTMENT)                           15975100
                                                                                                ----------
            LEVELIZED ANNUAL REVENUE REQUIREMENTS                                                34570700

            EQUIVALENT LEVELIZED UNIT REVENUE REQUIREMENTS, MILLS/KWH (MW SCRUBBED)                12.57

            LEVELIZED DOLLARS PER TON OF SULFUR REMOVED                                           7451.43
-------------------------------------------------------------------------------------------------------------------------
        HEAT RATE  10000. BTU/KWH     -     HEAT VALUE OF COAL      8200 BTU/LB     -      COAL RATE   1760700 TONS/YR
      0.7% S WESTERN SUBBITUMINUS 500 MW -- BASE --
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(Continued)